This is a reproduction of a library book that was digitized by Google as part of an ongoing effort to preserve the information in books and make it universally accessible.

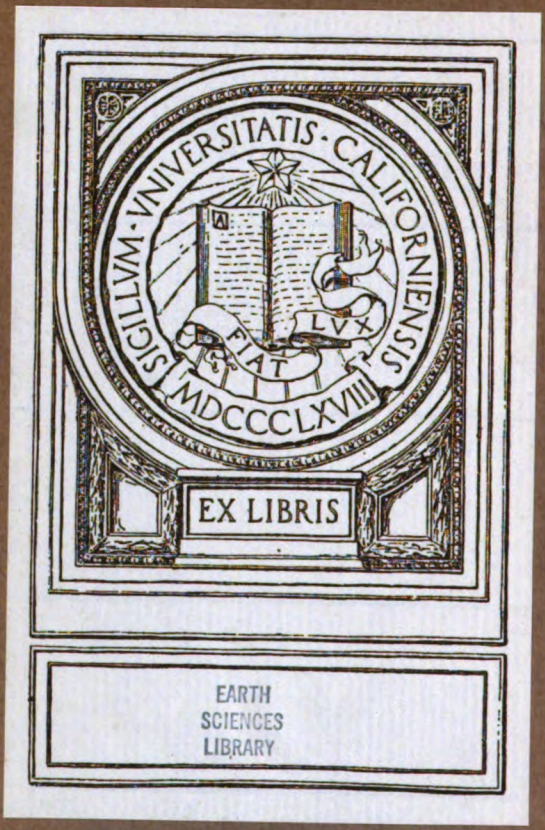
Google™ books

https://books.google.com

Digitized by Google

BERKELEY
LIBRARY
UNIVERSITY OF
CALIFORNIA

EARTH
SCIENCES



Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

Digitized by Google

Digitized by Google

TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY

OF GLASGOW.

UNIV. OF CALIFORNIA

VOL. XVII.

1925-1926.

GLASGOW: PUBLISHED BY THE SOCIETY,
AT ITS ROOMS, 207 BATH STREET.
1927.

Digitized by Google

QE1
G46
v.17
EARTH
SCIENCES
LIBRARY

UNIV. OF
CALIFORNIA

Digitized by Google

CONTENTS—VOLUME XVII., PART I.

PAPER		PAGE
I.	The Glaciers of Spitsbergen. By G. W. Tyrrell, A.R.C.Sc., F.G.S., F.R.S.E.,	1
II.	The Fracture of Homogeneous Media. By James W. French, D.Sc., F.Inst.P.,	50
III.	Some Fissures in the Strata of Benmore Hill, Cowal. By John M'Gregor,	69
IV.	Notes on the Chitons of Woodmill. By Robert Dunlop,	75
V.	Burrows, Trails, and Tracks in Sandstone, Charleston, Fife. By Robert Dunlop,	77
VI.	Notes on Four Nautili. By Robert Dunlop,	78
VII.	An Example of River Action and its Bearing on Plant Distribution. By Donald Patton, M.A., B.Sc.,	80
VIII.	The Parallel Roads of Loch Tulla. By J. C. Gregory, B.Sc.,	91
IX.	The Physical Conditions under which the Deutozoic Rocks of Scotland were Deposited. By Prof. Peter Macnair, F.G.S.,	105
	Proceedings of the Society, 1919-1922,	146
	Office-Bearers for Session 1921-1922,	168

735159

Digitized by Google

Digitized by Google

CONTENTS—VOLUME XVII., PART II.

PAPER		PAGE
I.	The Red Sandstone of Toward. By James Stark, - -	169
II.	The Geology of a Composite Intrusion at Bennan, South Arran. By J. V. Harrison, B.Sc., - - - - - -	173
III.	Megatherium Bones found at Quishuarcancha, Peru. By J. A. W. Murdoch, - - - - - - - - - -	181
IV.	The Geology of Iceland. By Martin A. Peacock, B.Sc., L.R.A.M., - - - - - - - - - - -	185
V.	The Carboniferous Strata below the Top Hosie Limestone in North Ayrshire. By J. E. Richey, M.C., B.A., -	204
VI.	Notes on the Geology of the Tarbert District of Loch Fyne. By W. J. M'Callien, B.Sc., - - - - - - -	233
VII.	The Permian Breccia of Arran. By B. Hilton Barrett, M.A., B.Sc., - - - - - - - - - - -	264
VIII.	A Contribution to the Petrography of Iceland. By Martin A. Peacock, B.Sc., L.R.A.M., - - - - - - -	271
	Proceedings of the Society, 1922-1924, - - - - -	334
	Office-Bearers for Session 1925, - - - - - -	348

Editors—DAVID B. DUNCANSON, B.Sc.
JOHN WEIR, M.A.

Digitized by Google

Digitized by Google

CONTENTS—VOLUME XVII., PART III.

PAPER		PAGE
I.	The Structure of South Knapdale. By W. J. McCallien, B.Sc., ...	377
II.	On an Occurrence of Sanguinolites abdenensis. By W. Manson	349
III.	Note on a Rhinoceros Bone from the Glacial Sands of Cadder. By W. E. Swinton, B.Sc., F.G.S.	395
IV.	Moraines, Boulder Clay and Glacial Sequence of S.W. Scotland. By Prof. J. W. Gregory, F.R.S.	354
V.	Description of the Sand Deposit at Hungryside, Torrance. By W. R. Flett	396
VI.	Petrography of the Hungryside Sands. By W. Robert Flett, ...	398
VII.	The Petrography of the Clyde Alluvium. By Hilton Barrett, M.A., B.Sc., F.G.S. ..	402
VIII.	The Apatites in Sedimentary Rocks as Indicators of the amount of Atmospheric Carbonic Acid in the periods of deposit. By William Mackie, M.A., M.D., LL.D.	407
IX.	On the Occurrence of two Boulders of Kentallenite at Greenoch. By Rev. J. D. McCulloch, F.R.S.E.	422
X.	The Dolerite Boss of Sithan-t-Sluain. By James Holmes, B.Sc.	426
XI.	Reported Metamorphic Zone at Castlefern. By Prof. J. W. Gregory, F.R.S.	438
XII.	A Preliminary Study of the World Geometry of Structure Lines. By A. Stevens, M.A., B.Sc.	440
	Obituary on Dr. R. Kidston. By Dr. D. Patton ..	464
	Proceedings of the Society, 1924-26, ...	466
	Office-bearers for Session 1926-1927	476

Digitized by Google

Digitized by Google

LIST OF ILLUSTRATIONS—VOLUME XVII., PART I.

Plates I. to XIII. Glaciers of Spitsbergen.

Plates XIV. to XVI. Fracture of Homogeneous Media.

FIGURES IN TEXT.

	PAGE
Glaciers of Prince Charles Foreland,	17
Horseshoe Glaciers,	23
Section of Nordenskiöld Glacier,	36
Diagram of Land Tilting,	42
Ekholm Valley,	44
Sassen River Mouth,	45
Glass Fracture Sections,	54
„ Plan,	55
Sleek on glass,	56
Scratch on glass,	56
Percussion cracks,	56
„ „	58
Knife cut on glass,	57
Lunar Craters (Diagram),	60
„ „	61
Map of Benmore Fissures,	70
Diagrams of Fissures,	71, 72, 73
Chiton (restored),	75
Maps of Clyde Meander,	84, 88
Map of Parallel Roads of L. Tulla,	92
Drawing of "Road,"	94
Maps of British Isles (Devonian),	132, 134, 143

Digitized by Google

Digitized by Google

LIST OF ILLUSTRATIONS—VOLUME XVII., PART II.

PLATE		PAGE
I.	Pelvis of Megatherium,	184
II.	Bones of Megatherium,	184
III.	Drawings of Rock Sections,	295
IV.	,, ,, ,,	304

DIAGRAMS IN TEXT.

		PAGE
Fig. 1.	Sequences of Limestones below the Top Hosie in North Ayrshire and South Renfrewshire,	213
,, 2.	Map of Land and Sea Areas near close of Calciferous Sandstone Times,	215
,, 3.	Vertical Section to illustrate overlap in the Stewarton District,	220
,, 4.	Vertical Section to illustrate overlap in the Galston District,	222
,, 5.	Horizontal Section across South portion of Eastern Land of Fig. 2 at close of Lower Limestone Times,	225
,, 6.	Sketch showing Glenralloch,	235
,, 7.	Burn Section in Clay, North of Ashens,	236
,, 8.	Crush Breccia, Mealdarroch Point,	241
,, 9.	Epidiorite, Quartzite and Schists,	242
,, 10.	Schist Foldings,	243
,, 11.	Limestone and Associated Rocks,	244
,, 12.	Sketch of Alluvial Hollow, Barnellan,	245
,, 13.	Quartzite and Phyllite,	253
,, 14.	Quartzite and Lamprophyre,	254
,, 15.	Map of Geology of Tarbert,	262
,, 16.	Section from Skipness to Ardrishaig,	263
,, 17.	Map of S.W. Iceland,	273
,, 18.	Diagram of Rock cooling,	284
,, 19 and 20.	Maps of Torfa Jökull,	301
,, 21.	Variation Diagram of Igneous Suite,	326

Digitized by Google

Digitized by Google

LIST OF ILLUSTRATIONS—VOLUME XVII, PART III.

			PAGE
Plate	I.	Rhinoceros Bone from the Glacial Sands of Cadder	*to face* 395
,,	II.	Summit of Sithan-t-Sluain from the North	,, 426
,,	III.	Photomicrographs prepared by Mr. D. M. Filshill, to illustrate The Dolerite Boss of Sithan-t-Sluain	,, 429
,,	IV.	,, ,, ,,	,, 431

Digitized by Google

FIGURES IN TEXT.

		PAGE
Figure 22.	Map of central Valley of Scotland	350
,, 23.	.. ..	352
,, 24.	.. ..	355
,, 25.	.. ..	379
,, 26.	.. ..	383
,, 27.	Fold in Erin Quartzite, Allt Mor	384
,, 28.	.. ..	385
,, 29.	Section across the Erins Quartzite	386
,, 30.	Section from Kilberry to West Loch Tarbert	390
,, 31.	Section across Loch Awe Group and Ardrishaig Group	392
,, 32.	.. ..	419
,, 33.	Diagram across Fairy Knowe	427
,, 34.	Diagram of relative distribution of rock types	429
,, 35.	" Parallel " Great Circles	442
,, 36.	Maps on various projections showing the same three great circles	443
,, 37.	Trend line of Rockies, Andes, Sumatra, Timor, Java	448
,, 38.	Some Australian structure lines	452
,, 39.	Map of Arctic regions on Gnomonic Projections	453
,, 40.	Poles of the Appalachian, Labrador and Sumatra circles..	454
,, 41.	Fracture pattern	461

Digitized by Google

TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY

OF GLASGOW.

UNIV. OF CALIFORNIA

VOL. XVII.—PART I.

1919-1922.

GLASGOW: PUBLISHED BY THE SOCIETY,
AT ITS ROOMS, 207 BATH STREET.
OCTOBER, 1922.

William Hodge & Co., Ltd.,] [*Printers, Glasgow.*

PRICE 7s. 6d.

Digitized by Google

UNIV. OF
CALIFORNIA

Digitized by Google

TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

No. I.—The Glaciers of Spitsbergen. By G. W. Tyrrell, A.R.C.Sc., F.G.S., F.R.S.E., Lecturer in Geology, University of Glasgow.

TABLE OF CONTENTS.

	PAGE
Introduction,	2
List of Literature,	3
Classification of Spitsbergen Glaciers,	5
Island Ice.	11
Highland Ice,	11
Plateau Ice (Icelandic-Norwegian type),	14
Carapaces,	15
Ice-foot (Shore Ice),	16
Piedmont Glaciers,	17
Reticular Glaciers,	18
Dendritic Glaciers,	20
Transection Glaciers,	20
Valley Glaciers,	21
Expanded Foot Glaciers,	21
Niche Glaciers,	22
Horseshoe Glaciers,	22
Corrie Glaciers,	23
Cascade Glaciers,	24
Incidence of Glaciation in Spitsbergen in Relation to Meteorology and Topography,	25
Advance and Recession of Spitsbergen Glaciers,	27
Some Surface Features of Spitsbergen Glaciers,	32
Moraines,	32
Ablation Effects,	33
Drainage Effects,	34
Movement Effects,	34
The Formation of Boulder Clay,	35
The Earlier Glaciation,	37
Some Erosional Effects of Past and Present Glaciation,	43
Corries,	43
Joint Control,	44
Facetted Spurs,	44
Overflow Channel in Sassen Valley,	45
Through Valleys,	45
Explanation of Plates,	46

Digitized by Google

Introduction.

The object of this paper is to record glaciological observations made by the author in Spitsbergen during the summers of 1919 and 1920, when he was prospecting on behalf of the Scottish Spitsbergen Syndicate, of Edinburgh; and also to summarise the more important work on Spitsbergen glaciers that has been done since the classic investigations of Professors Garwood and Gregory.

Spitsbergen is the most accessible polar land; it is highly glaciated, its glaciers covering a great range of types from icecaps of small dimensions to corrie glaciers and dead ice slabs on cols. All these are easily accessible to intensive study, which is of the utmost importance to British glaciology, inasmuch as Spitsbergen gives us a present-day picture of a state of affairs that must have obtained during the decay of the great Pleistocene ice sheet of our own country. Mr. G. W. Lamplugh (1911, p. 219)[1] has remarked on the lithological similarities between the stratified rocks of Spitsbergen and of the British Isles, especially in their bearing on the origin of boulder clay.

The homology between the geological structure, stratigraphy, and geomorphology of Spitsbergen, and of the British Isles, is very close, and deserves to be stressed in relation to the study of Pleistocene glaciation in the latter country. Just as in Britain, the hard ancient rocks of complicated structure in Spitsbergen are to be found in the northern and western mountains; Carboniferous limestones occupy extensive tracts in the central regions about Ice Fiord; whereas younger rocks of ages ranging from Triassic to Cainozoic occur in the eastern and southern parts. In these formations the structures are simple and uniform over large areas, the beds being horizontal or gently monoclinal. As Mr. Lamplugh remarks, the later formations are mainly composed of soft rocks which easily break down into talus and finally into small rock debris and mud, forming material ready-made for easy conversion into boulder clay.

As in Britain, the highest parts of Spitsbergen are in the

[1] For references see list of literature, p. 3.

Digitized by Google

west and north, the elevations in general decreasing towards the east and south. In the west, north-west, and north-east the mountains are mainly of the spiry Alpine type. In the central and eastern regions, however, flat-topped mountains and elevated plateaus alternate with widely-opened flat-bottomed valleys. Towards the south and south-east the areas of the plateau tops become much reduced, and broad mountain ridges and knots alternate with wide ramifying valley systems (Pl. XIII., Fig. 1). The physiographic stage here is one of maturity as compared with the old age conditions of the eastern and southern parts of the British Isles.

These striking homologies between the lithology, stratigraphy, geological structure, and physiographic conditions of Spitsbergen and Great Britain will afford the greatest assistance in elucidating the Pleistocene glaciation of the latter country, when the present-day glaciation of Spitsbergen has been studied in the close detail that it deserves in view of its importance, not only to British, but to European Pleistocene glaciation in general.

The writer found opportunities for the study of Spitsbergen glaciers in three regions: at the head of, and along, Klaas Billen Bay, on the fringe of the New Friesland highland ice, whence large valley- and tide-water-glaciers, such as the Nordenskiöld Glacier, press down to the sea; in Prince Charles Foreland, the eastern coast of which is covered by typical, though small, piedmont glaciers; and in the Stor Fiord region on the east coast, where the evidence of recent advance and retreat of great glaciers can be especially well observed.

The chief sources of recent information concerning the glaciers of Spitsbergen are given in the list of literature below, beginning with the work of Garwood and Gregory mentioned in the introduction.

List of Literature.

The list is arranged in order of date of publication.

Garwood, E. J., and Gregory, J. W.
"Contributions to the Glacial Geology of Spitsbergen." *Quart. Journ. Geol. Soc.*, 1898, 54, pp. 197-225.

Conway, Sir Martin.
"With Ski and Sledge over Arctic Glaciers." London: J. M. Dent & Co., 1898, pp. 235.

Digitized by Google

Garwood, E. J.
"Additional Notes on the Glacial Phenomena of Spitsbergen." *Quart. Journ. Geol. Soc.*, 1899, 55, pp. 681-691.

De Geer, Baron G.
"Die Gletscher von Spitzbergen." *Verh. d. vii. Intern. Geogr. Kongr., in Berlin*, 1899, 1900, pp. 299-302.
"Om östra Spetsbergens Glaciation under Istiden." *Geol. Fören. Stockholm Förh.*, 1900, 22, pp. 427-436.

Conway, Sir Martin.
"Measurement of an Arc of Meridian in Spitsbergen." *Nature*, 1903, 67, pp. 536-8; see also *Scottish Geogr. Mag.*, 1903, 19, 381-2.

De Geer, Baron G.
"A Geological Excursion to Central Spitsbergen." *Guide de l'excursion au Spitsberg xie Géol. Congr. Internat., Stockholm.* 1910, pp. 23.

Cole, G. A. J.
"Glacial Features in Spitsbergen in Relation to Irish Geology." *Proc. Roy. Irish Acad.*, 1911, 29B, pp. 191-208.

Lamplugh, G. W.
"On the Shelly Moraines of the Sefström Glacier and Other Spitsbergen Phenomena Illustrative of British Glacial Conditions." *Proc. Yorks. Geol. Soc.*, 1911, 17, pp. 216-241.

Drygalski, E. von.
"Spitzbergens Landformen und Ihre Vereisung." *Abh. K. Bayer. Akad. Wiss.*, 1911, 25, Abh. 7, pp. 1-61.

Isachsen, G.
"Rapport sur l'expédition Isachsen au Spitsberg, 1909-10." *Vidensk. Selsk. Skr. I. Math.-Nat. Kl.*, 1912, No. 15, p. 99.

Staxrud, A. and Hoel, A.
"Résultats généraux de l'expédition norvégienne au Spitsberg (1911-12)." *La Géogr.*, Paris, 1913, 27, pp. 99-108.

Philipp, H.
"Geologische Beobachtungen, in Ergebnisse der W. Filchnerschen Vorexpedition nach Spitzbergen." *Peterm. Mitth. Ergänz.*, 179, 1914, pp. 13-46.

Hoel, A.
"Résultats généraux de l'expédition norvégienne au Spitsberg en 1913." *La Géogr.*, Paris, 1914, 29, pp. 177-182.

Hoel, A.
"Résultats des Campagnes Scientifiques accomplies sur son yacht, par Albert, 1er Prince Souverain de Monaco. Fasc. 42. Exploration du Nord-ouest du Spitsberg." Pt. 3, Géologie. Monaco: 1914, pp. 64.

Isachsen, G.
"Travaux Topographiques de l'expédition Isachsen, 1909-1910." *Vidensk. Selsk. Skr. I. Math.-Nat. Kl., Kristiania*, 1915, No. 7, pp. 63.

Staxrud, A., and Hoel, A.
"Résultats de l'expédition norvégienne au Spitsberg en 1914." *La Géogr.*, Paris, 1915, 30, pp. 277-9.

Craig, R. M.
"Outline of the Geology of Prince Charles Foreland, Spitsbergen." *Trans. Geol. Soc., Edinburgh*, 1916, 10, pp. 276-88.

Peach, A. M.
"The Pre-Glacial Platform and Raised Beaches of Prince Charles Foreland." *Ibid.*, pp. 289-307.

Digitized by Google

Hoel, A.
"Observations sur la vitesse d'écoulement et sur l'ablation du Glacier Lilliehöök au Spitsberg." *Vidensk. Selsk. Skr. I. Math.-Nat. Kl., Kristiania*, 1916, No. 4, pp. 29.

Hoel, A., and Rövig, S.
"Rapport prélim. de l'expédition norvégienne de 1917 au Spitsberg." *La Géogr.*, Paris, 1918, 32, pp. 96-101.

Hoel, A.
"Rapport prélim. de l'expédition norvégienne de 1918 au Spitsberg." *Ibid.*, pp. 231-5.

De Geer, Baron G.
"Om Spetsbergens Natur i Sveagruvans Omnejd." *Ymer*, 1919, 240-77.

Wordie, J. M.
"Present-day Conditions in Spitsbergen." *Geogr. Journ.*, 1921, 58, pp. 25-49.

Tyrrell, G. W.
"Geographical Observations in Spitsbergen, 1919 and 1920." *Scott. Geogr. Mag.*, 1921, 37, pp. 227-42.

Tyrrell, G. W.
"The Pre-Devonian Basement Complex of Central Spitsbergen." *Trans. Roy. Soc., Edinburgh*, 1922, 53, pt. 1, pp. 209-229.

For maps of the regions dealt with in the following see Craig and Peach (1916), Wordie (1921), and Tyrrell (1921) for Prince Charles Foreland; De Geer (1910) and Isachsen (1915) for Ice Fiord and the western coast; J. Mathieson in R. N. R. Brown, "Recent Developments in Spitsbergen," *Scott. Geogr. Mag.*, XXXVI., 1920, map p. 116, and Tyrrell (1922) for the Klaas Billen Bay region; and Philipp (1914) and De Geer (1919) for the Stor Fiord region.

Classification of Spitsbergen Glaciers.

Since the range of Spitsbergen glacier types is almost co-extensive with that of glaciers in general, their relations are best exhibited through a general classification of glaciers. J. M. Wordie (1921) has classified Spitsbergen glaciers on this basis, utilising for that purpose Mr. R. E. Priestley's as yet unpublished classification embodied in the Glaciology Memoir of the Scott Antarctic Expedition, 1910-13. Wordie's slightly modified version is shown below, the types found in Spitsbergen being indicated by italics.

Supply.	Movement.	Wastage.
Continental Ice (cap).	*Valley Glacier.*	*Expanded Foot.*
Island Ice (cap).	*Wall-sided Gl.*	*Piedmont.*
Highland Ice (sheet).	*Cascading Gl.*	Glacier Tongue.
Cwm Glacier.	*Avalanche Gl.*	*Confluent Ice.*
Snowdrift Ice.		Shelf Ice or Barrier.

Digitized by Google

The classification regards an ideal ice mass as composed of areas of predominant supply, predominant movement, and predominant wastage. The first group, therefore, includes ice masses in which accumulation of ice and conservation of the underlying terrain are the main features; the second includes ice masses in which considerable movement and erosion of the underlying and adjacent land surfaces are predominant; and the third includes ice masses in which wastage and deposition of material upon the land surface are the most prominent features.

One may, however, look somewhat askance at a grouping which brings together continental glaciers and cwm glaciers; valley glaciers with avalanche glaciers; and expanded foot glaciers with barriers. It is not to be questioned but that an ideal ice mass (and many actual examples), starting at a high level and descending to a low level, may be divided as stated into areas of predominant accumulation, movement, and wastage; but whether that fact affords the best foundation for a genetic classification of glaciers seems to be dubious. If a genetic grouping requires that a piedmont mass, for example, is to be classified as it is because *at present* it is undergoing wastage, it is legitimate to assume that, in its early stages, when the ice was accumulating on the piedmont terrain, it belonged to the supply class; and that if an advancing piedmont were found at the present day it would be placed in the supply group. Similarly a valley glacier in a stage of rapid retreat, in which wastage was obviously the main feature, would have, in this mode of classification, to be placed in the wastage group. Priestley's classification, therefore, as expounded by Wordie, seems to be based on secondary, accidental, and adventitious circumstances in the natural history of ice masses. A more fundamental factor determining the difference between a piedmont glacier and a corrie glacier, or between either of these and highland ice, is the topography of the underlying land surface. If the mountain wall were not abruptly succeeded by a flat foreland, the ice descending the mountain valleys would simply form a series of disconnected valley glaciers. It is only the topographical circumstance of a plain on which the mountain valleys debouch which enables the ice to accumulate in the form that we recognise as a piedmont glacier. Other factors, such

Digitized by Google

as the more or less complete obliteration of the land surface by the ice; the stage reached in the advancing or receding glacial hemi-cycle; and the conditions affecting accumulation, movement, and wastage of ice, all have their effect on the form and nourishment of ice masses.

Since it is mainly on a topographical basis, the writer prefers E. von Drygalski's classification of Spitsbergen glaciers to Wordie's, although it certainly does not cover the entire field. Drygalski (1911, p. 18) groups Spitsbergen glaciers as follows:—

Cascade Glaciers (Stufenvereisung).
Niche Glaciers (Nischengletscher).
Valley Glaciers.
Highland Ice Caps.

The cascade glacier type includes ice masses held in "staircase" forms of cliffs and steep valley sides, and are found mainly on the step-formed walls of the sandstone plateaux of Nordenskiöld Land. The niche glacier type includes all ice masses lying in hollows upon the valley walls, or the peaks and ridges. Highland ice caps, represented by the New Friesland ice, are sheets covering elevated hilly or undulatory surfaces.

Turning now to recent classifications of glaciers in general as bases for a classification of Spitsbergen glaciers, we have to consider those of W. H. Hobbs and O. Nordenskiöld. Hobbs[2] first makes a fundamental distinction between continental glaciers and mountain glaciers, the former having their surface forms independent of the topography of the underlying terrain, and having no rock exposed above their higher levels. They also differ from mountain glaciers in their vastly larger dimensions and in their mode of alimentation. Mountain glaciers are further classified in a sequence of forms depending, according to Hobbs, on decreasing alimentation, but also, as it appears to the writer, on the topography of the terrain upon which they are developed. The following is Hobbs' classification on this basis:—

Ice Cap type (Jökulls of Iceland).
Piedmont type (Malaspina Glacier).
Transection type (Yakutat Glacier).

[2] Characteristics of Existing Glaciers, 1911, pp. 6-8, 41-58.

Digitized by Google

Expanded Foot type (Davidson Glacier).
Dendritic type (Baltoro Glacier).
Hanging Glaciers.
Cliff Glacierets.
Tide-water type.
Radiating (Alpine) type.
Horseshoe type (Mt. Lyell Glacier).

This list should be completed by the addition of the

Nivation type (=Snowdrift Ice) and
Inherited Basin type (with several sub-types),

which, according to Hobbs, do not fall in with his arrangement in order of decreasing alimentation (*Char. Exist. Gl.* p. 41).

The latest classification by O. Nordenskiöld[3] is as follows:—

A. *Lowland Glaciers.* Apart from a relatively small conflux of ice inland, these are formed mainly near sea level.
   1. *Shelf Ice.* Level ice fields covering the lowlands and the adjacent sea floor.
   2. *Ice-foot Glaciers.* Banded ice masses covering coastal shelves and equivalent to the inner margins of shelf ice.

B. *Highland Glaciers.* Ice moving from a high region to a lower, frequently with a steep intermediate slope in some part; an accumulation region can frequently be separated from a discharge region.

I. *Continental Glaciers.* Ice with surface form and motion essentially independent of the form of the subjacent terrain.
   3. *Inland Ice.* Marginal zone and its protuberances small in proportion to the total mass.
      ["Inland Ice" here appears to be used as a term equivalent to "Continental glacier."]

II. Forms transitional between I. and III.
   4. *Cap-like Ice Islands.* Ice covering small islands, and pushing out to sea over the terrain and the coast-line [=Island Ice].
   5. *Spitsbergen type.* Ice covering the greater part of a mountain region, sometimes in such large masses

[3] Bidrag till Glaciärnarnas Systematik. *Geol. Fören. Stockholm Förh.*, 1918, 40, pp. 547-61.

Digitized by Google

that they become independent of the form of the subjacent terrain, which, however, in general, determines the surface form of the ice.

6. *Plateau Ice* (Norwegian-Icelandic type). Form recalls that of inland ice, but is mainly determined by the subjacent plateau terrain; wastage partly without the formation of separate discharge tongues.

III. *Mountain Glaciers.* The Alpine type in an extended sense. The ice is divided up into small streams situated on valley floors, and separated by high, partly ice-free summits and ridges. The most important sub-types are

7. *Alaska type* (Piedmont or Foreland Glaciers).
8. *Dendritic type.* Whole valley system full of ice.
9. *Fan type* (Alpine type in narrow sense). Connected ice masses within the uppermost parts of valleys, uniting in a common tongue lower down.
10. *Horseshoe type.* Separated niche glaciers surrounding a mountain top, or the uppermost part of a valley.

This classification certainly utilises the topographic form of the terrain on which the ice is developed as its main basis, and might be used with considerable facility for the grouping of Spitsbergen glaciers.

The writer, however, ventures to classify glaciers according to a new scheme, the main feature of which is the recognition of the different development of glacier form, motion, accumulation, and wastage, in regions of *high relief* as compared with those of *low relief*. He first separates those ice masses whose forms and motions are wholly or mainly independent of the nature of the subjacent terrains, from those whose forms and motions are partly or wholly dependent upon the topography of the underlying land surfaces. The latter group is then subdivided according to whether the ice is developed on terrains of low relief or high relief, the sequence of forms being that which would be developed in either case during successive stages of the receding hemi-cycle of glaciation. If the land surface be imagined first to be covered with a continental glacier, the form, motion, nourishment, erosion-, and conservation-effects of the ice masses which develop in successive stages of the re-

Digitized by Google

ceding cycle of glaciation, may be conceived as depending mainly on whether the terrain beneath is one of high relief or of low relief. The tabular statement of the classification is as follows:—

A. Ice masses whose characters are wholly or mainly independent of the topography of the subjacent terrain.
   1. *Continental Glaciers* (Greenland, Antarctica)
   2. *Island Ice* (Northeastland).
   3. *Highland Ice* (New Friesland).

B. Ice masses whose characters are partly or wholly dependent on the topography of the subjacent terrain.

I. Ice masses on terrains of mainly low relief.
   1. Ice masses on elevated terrains of low relief.
      (*a*) *Plateau Ice* (Icelandic-Norwegian type); Hobbs' ice-cap type probably to be included.
      (b) *Carapaces* (see p. 15).
   2. Ice masses developed on low-relief lowlands.
      (*a*) *Shelf Ice.*
      (*b*) *Ice-foot Glaciers.*
      (*c*) *Shore Ice* (Ice-foot).
      (*d*) *Piedmont Glaciers.* If the ice unit be regarded as including also the mountain valley feeders, this type may be taken as transitional to the high-relief forms (II.).

II. Ice masses developed on terrains of mainly high relief. (Mountain glaciers of Hobbs.)
   (*a*) *Reticular Glaciers* (see p. 18), including Hobbs' transection type.
   (*b*) *Dendritic Glaciers.*
   (*c*) *Valley Glaciers*, including expanded-foot glaciers.
   (*d*) *Niche Glaciers*, including corrie glaciers, horseshoe glaciers, cascade glaciers, snow-drift ice, &c.

The glacier types developed in an advancing hemi-cycle of glaciation may conform to a similar scheme; but since practically all the world's glacier regions are now in a phase of recession, it is not possible to develop it.

Further remarks and observations elucidatory of the above classification will be made in the succeeding sections, in which the classification is applied to the presently known glacier types of Spitsbergen.

Digitized by Google

Island Ice.—Since there are only two continental glaciers, namely, those of Greenland and Antarctica, no further reference to this type need be made. Island ice, however, is represented by the cap covering the greater part of Northeastland. The writer was not able to visit Northeastland, and will only, therefore, refer the reader to Hobbs' excellent summary of A. E. Nordenskiöld's description of his crossing of the island with Palander in 1873.[4]

Highland Ice.—A large part of Spitsbergen is covered by highland ice, a form which is held to develop in the early stages of the receding glacial hemi-cycle, when the continental ice covering is thinning, and the surface of the ice begins to show the influence of the subjacent topography, some parts sagging into the hollows, others rising above the general level on submerged ridges and plateaux. The divergence between glacier forms developing on low-relief and high-relief terrains respectively is least at this stage, but increases gradually with later stages.

On mainly low-relief terrains the early stages of the receding hemi-cycle of glaciation will be characterised by thin ice sheets following the undulations of the ground beneath, except where central or local thickening may obscure the relations. Comparatively broad areas of the higher parts of plateaux may break through the ice sheet towards the margins of the mass. On terrains of mainly high relief, the surfaces of the ice forms will undulate more sharply than in the above case, and there will be a tendency for peaks and narrow ridges to appear above the ice.

H. Philipp (1913) strongly emphasises the influence of the subjacent topography on the development of the ice. He instances the contrast in ice forms in the regions north and south of the Von Post Glacier. Bünsow Land, to the north, is a valley glacier region showing wide valleys alternating with sharp ridges or small plateaux. A coherent ice field is thus impossible under present conditions. The ice is in the form of large, separate, valley glaciers, with an occasional small "ice-cap" (carapace ?, see p. 15). In Conway Land, to the south, however, there are no broad, well-individualised valleys, but a gently sloping plateau surface covered by a firn

[4] Characteristics of existing Glaciers, 1911, pp. 112-16.

Digitized by Google

field which may reach an area of 500 sq. kms. This joins the Von Post Glacier on a broad front which is broken only by a few nunataks (Philipp, 1914, Pl. I.). Philipp compares this development with the Norwegian plateau ice, which differs, however, from the Conway Land type in that it sends out short, blunt protrusions down adjacent valleys.

In Sabine Land, to the east of the Von Post Glacier region, glaciation is at present more intense than in the above regions, mainly because of severer climatic conditions. The ice covering is largely independent of the form of the terrain. There is no sharp contrast between the firn field and the individualised valley glacier; from all sides the firn envelops and submerges the flanks of the mountains. Only the upper ridges and steeper peaks project from the ice (Philipp, 1914, Pl. II.). Philipp identifies this form with the Spitsbergen type of O. Nordenskiöld. Near the coast nunataks appear, and the outflow is individualised into vast valley glaciers, such as the Negri and Hayes Glaciers. Wordie (1921, p. 39) regards the Negri Glacier as a case of Priestley's *confluent ice*, comparable to a piedmont glacier, except that it may be afloat at its termination, and has its shape determined by rock obstacles in its course.

The Negri Glacier occurs on the south-eastern margin of the New Friesland plateau, which has a gradual slope in that direction towards the Stor Fiord. The nunataks near its termination, and its marginal heights, are all of plateau form. In the writer's opinion, the Negri Glacier is simply the outflow of the New Friesland highland ice, brought down to sea level by the gradual slope of the plateau to the south-east, and entering the sea on a very broad front. It can scarcely be regarded as a valley glacier, although the shape and disposition of the nunataks indicate broad, shallow depressions separated by low plateaux, submerged by the ice. The plateau character of the Negri ice is indicated by the large, tabular, Antarctic-like icebergs to which it gives rise (Pl. V., Fig. 2).

Drygalski recognises "highland ice caps" (1911, p. 20). He says they are mostly confined to Urgebirge terrains with their high undulating surfaces. They have grown by the coalescence of ice masses due to the collection of snow in more or less wind-sheltered hollows. According to Drygalski, New

Digitized by Google

Friesland exhibits an almost uniform ice cap, broken only by single rock peaks or ridges. The ice arches down over the edges of the plateau bordering the adjacent coasts, and sends down steep glaciers through the gaps. The New Friesland ice mass, covering a vast area in the region between Wijde Bay on the west, Hinlopen Strait on the east, and Sabine Land to the south, is the type example of O. Nordenskiöld's "Spitsbergen type." While the form of the ice sheet frequently follows that of the subjacent topography, in some parts of the region it may be so thick as to be uninfluenced in this way. According to Wordie (1921, p. 38), the New Friesland mass is highland ice, which, by his definition, is a thin, continuous ice sheet, with its upper surface conforming in the main to the major undulations of the subjacent terrain. Wordie believes that O. Nordenskiöld's Spitsbergen type is intermediate between continental or island ice and highland ice; the writer's observations, however, lead him to confirm O. Nordenskiöld's diagnosis of the New Friesland mass, in that it has a thick central part the surface form of which is entirely independent of the topography on the underlying terrain. The writer was favoured on two occasions in getting beautifully clear views over the west central and southern parts of the New Friesland ice mass from summits in the De Geer range at the head of Klaas Billen Bay. The general nature of the view is shown by the sketch published in another paper (Tyrrell, 1922, Fig. 2). The view is bounded to the north by the dark massive Pre-Devonian mountains on the east side of Wijde Bay. A short stretch with an ice horizon bounds these on the east; and then to the N.N.E. is seen a high range of probably Pre-Devonian mountains, which doubtless belong to the Newton-Chydenius range, and include the highest summits in Spitsbergen. What appear to be Carboniferous or Hecla Hook peaks occur east of these, but to the north-east generally there is a high convex sky-line of ice, above which there are no projecting peaks.

The main outflows of the New Friesland mass in this region are the Nordenskiöld and Mittag-Leffler Glaciers, discharging respectively into Klaas Billen Bay and into Wijde Bay. The former is broken by two great Carboniferous nunataks, Mts. Terrier and Ferrier (Pl. VIII.), forming the southern part of a

Digitized by Google

line of similar nunataks which is continued to the north-west past the De Geer range. The Mittag-Leffler Glacier is broken by a few, small, Pre-Devonian nunataks. The mountain ridges on the south side of the Nordenskiöld Glacier, and those of the De Geer group, gradually pass under the ice sheet towards the north-east, but their courses can still be traced for a considerable distance by the ridging and swelling of the ice over their buried continuations. These features, however, are gradually lost beneath the distant central convexity, where the ice is clearly thick enough for its surface form to be entirely uninfluenced by the subjacent topography (Wordie, 1921, Pl. p. 32).

Both in Barents and Edge Islands there appear to be ice sheets of small dimensions comparable with O. Nordenskiöld's Spitsbergen type. Both islands consist of tabular mountains or plateau areas of moderate elevation separated by widely opened valleys. Looking up the western valleys from the Stor Fiord, one obtains an occasional glimpse through the ever-present mists of high convex sky-lines of ice in the interior. The western edges of these ice masses were reached by J. M. Wordie (1921, p. 35). They discharge mainly to the east over very broad fronts, forming glaciers of dimensions comparable to those of the Negri Glacier. The western sides of the islands are almost ice-free, the only considerable glacier descending to the Stor Fiord in Barents Island being the vigorous Duckwitz Glacier (see p. 29).

Some parts of the western and north-western regions of Spitsbergen, especially those to the north and east of Kings Bay, appear to be covered by ice masses approximating to highland ice, resting on a high-relief terrain. Such a region is that east of the Kings Highway—Svea Glacier ice-shed, illustrated by Holtedahl.[5]

Highland ice is then essentially the ice form developed in the first stage of deglaciation. The form and character of the ice masses thus developed depend to some extent on the subjacent topography, but not nearly so much as in later stages of deglaciation. Hence there is little difference between highland ice of low-relief and high-relief terrains.

Plateau Ice (*Icelandic-Norwegian type*).—These are sheets

[5] *Vidensk. Selsk. Skr. I. Math.-Nat. Kl., Kristiania*, 1912, No. 23, Pl. II., Fig. 2.

Digitized by Google

resting on more or less flat, plateau surfaces of relatively small size. They are of rather even thickness, usually not embossed like highland ice or island ice, occasionally even sagging in the centres, and in general following the undulations of the subjacent surface. They may be partially or wholly enclosed by slightly higher ground, or may be situated on plateaux surrounded by broad valleys and depressed areas. Typically they send out on all sides short, blunt lobes of ice, or occasionally much longer valley glaciers, through depressions in the edges of the plateau. Hobbs describes these forms as "ice-caps." Fig. 55 (p. 101) of his "Characteristics of Existing Glaciers" (1911) is an excellent diagram of the type.

In Spitsbergen the ice mass covering a large area in Conway Land, described by Philipp (p. 11), appears to be a good example of this type (Philipp, 1914, Pl. I., Fig. 2). It differs slightly from the typical Norwegian examples in that its protrusions join up laterally with the large trunk-stream of the Von Post Glacier. The region on the west side of Klaas Billen Bay, between Mimer Bay and Skans Bay, appears to be covered with plateau ice of this type (Pl. I., Fig. 3).

Carapaces.—The term *carapace* seems to have been loosely and casually applied to small ice-caps like those of Norway, Iceland, and the top of Kilimandjaro and other high, isolated mountains. Apparently it has never been strictly defined; and the writer believes it to be most usefully applied to ice masses which cover the rounded or flat tops of single mountains or hills. Near the east coast of Spitsbergen, in the relatively ice-free ground, there occur hills and small mountains of soft Triassic, Jurassic, and Cretaceo-Tertiary rocks, which have gently rounded summits. These are often covered with a thin sheet of ice which follows the rounded contour of the hill top, and sends small, blunt protrusions down depressions in the hill sides. They are slightly thicker in their central than in their marginal parts, and fit the top of the hill just as a schoolboy's cap fits his head. In fact, if the term "ice-cap" had not been preoccupied in so many ways, it would have exactly suited this form. The plan of these ice masses is approximately circular or elliptical, according to the shape of the hill top; but the blunt protrusions may give it an *amœboid* outline, to use an obvious comparison.

Digitized by Google

Slightly different are the ice masses which cover some of the flat-topped Carboniferous mountains of the Ice Fiord region. These are sometimes capped with a mass of ice which has an embossed surface, and is much thicker proportionately to its area than the carapaces above described. The ice often spills over the edge of the summit plateau, forming a cascade glacier. White Berg, on the eastern side of Klaas Billen Bay, near Anser Point, carries a typical example of this form (Pl. V., Fig. 1). Temple Mountain, too, appears to be covered with an ice mass of this kind.

Ice-foot (*Shore Ice*).—Of lowland low-relief ice forms, piedmont glaciers are the only prominent representatives in Spitsbergen. There is no shelf or barrier ice, or ice-foot glaciers in the sense of O. Nordenskiöld (p. 8), or of Hobbs.[6] The term ice-foot glacier, indicating an ice mass fringing a highland area, and accumulated by wind action, is rather badly chosen, as it suggests the ice-foot (shore ice) formed against the land either by spray, residual sea ice, or by collection of snow under the lee of sea cliffs. In Klaas Billen Bay the ice-foot lingered a month or two after the sea ice had disappeared. It formed a thin shelf sloping away from the marginal cliff, usually only a few feet wide, and about 3-4 feet above sea level. It was often possible to crawl under it for some feet. Its surface was so level and continuous that at first it formed an excellent highway along the shore. It appeared to be due partly to a thrust of sea ice against the land, and partly to the collection of snow. The thick ice-foot present in the Stor Fiord region was often distinctly stratified. During the annual thaw and breaking up, the sea ice contracts and breaks away from its elevated margins, leaving the latter adhering as a shelf to the cliffs (Pl. VI., Fig. 1). In the Stor Fiord region the ice-foot was frequently much thicker than in the Ice Fiord, and appeared to be a permanent feature of at least some parts of the coasts, the increase of temperature in the summer season not being sufficient to melt it (Pl. V., Fig. 3). Good examples were noted on the northern shore of Agardh Bay, and on the south side of Changing Point, Barents Island. These shelves were not continuous around the coasts; their

[6] Characteristics of Existing Glaciers, 1911, p. 209.

Digitized by Google

restricted distribution no doubt being due to the local incidence of wind action and snowfall.

Piedmont Glaciers.—The existence of a broad, elevated, marine platform around Spitsbergen shores up to at least 150 feet above sea level, particularly on the western side of the country, provides a favourable condition for the formation of

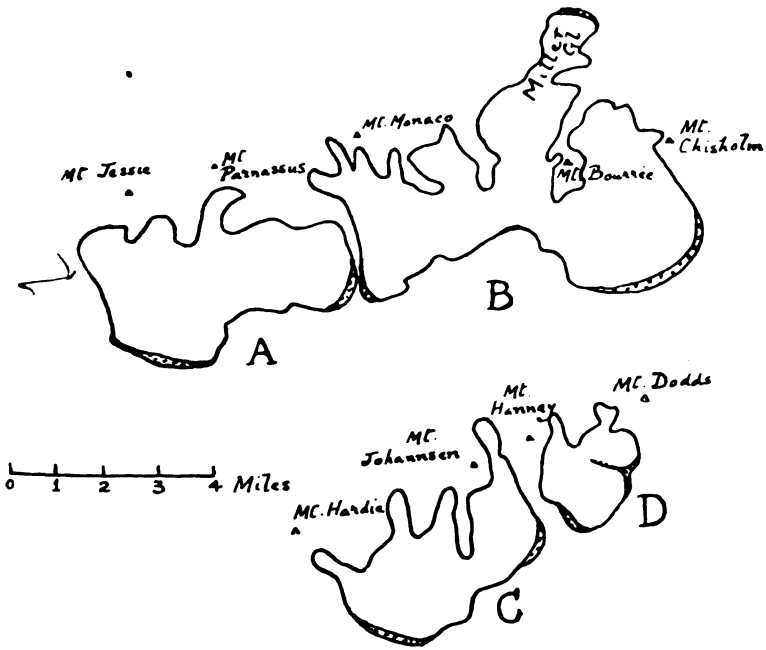


Fig. 1.—Outlines of the four piedmont glaciers of Prince Charles Foreland. (A) Buchanan Glacier; (B) Monaco (Murray) Glacier; (C) Sir Archibald Geikie Glacier; (D) James Geikie Glacier. (A) and (B), and (C) and (D), are respectively placed in their relative geographically positions (see p. 18).

small piedmont glaciers. The ice emerges from several adjacent valleys, and coalesces into an elongated mass on the flat, raised platform fronting the mountains. The best examples known to the writer are those on the eastern side of Prince Charles Foreland (Wordie, 1921, p. 39; Tyrrell, 1921, pp. 227-9 and sketch map). Here there are four piedmonts, which, in order from north to south, are the Monaco (Murray) Glacier, the Buchanan Glacier, the James Geikie Glacier, and the Sir

Digitized by Google

Archibald Geikie Glacier. The first two are separated by a narrow rock ridge known as The Nunatak; the latter pair are similarly separated by a rock ridge striking east from Mt. Hannay, and by about a mile of bare ice-free ground. The shapes and dimensions of these glaciers are shown in Fig. 1 (text). The Monaco (Murray) Glacier has been briefly described by R. M. Craig (1916, p. 286). It is fed by at least six valley and corrie glaciers descending from the mountains north of Mt. Monaco. Its termination to the north on the raised marine platform south of the Richard Lagoon is tapering and slender, and there is comparatively little moraine. At present the glacier here appears to be nearly stagnant.

The Buchanan piedmont occupies the ground between the rock ridges of The Nunatak and The Crocodile (see sketch map, Tyrrell, 1921). The ice reaches back into a number of large and small steep-sided hollows in the range of the Northern Grampians between Mt. Monaco and Mt. Jessie. It appears to be mainly fed by cascade glaciers, snow-avalanches (Wordie, 1921, p. 39), and probably also by continual snowdrift off the heavily covered range (Pl. II., Fig. 3). The two Geikie piedmonts are situated on the raised platform south of Ferrier Haven. The James Geikie Glacier is the smallest of the four, and is fed by two small valley glaciers and a number of corrie glaciers. The Sir Archibald Geikie Glacier is fed by several valley glaciers and some corrie and cascade glaciers from the mountains between Mt. Johannsen and Mt. Methuen (Pl. II., Fig. 2). These piedmont glaciers are all slowly accumulating and advancing. The bare ground between the Monaco and Buchanan masses, as also that between the two Geikie Glaciers, shows no sign of ever having been covered by ice; and the glacier fronts bounding them carry heavy moraines with the ice rising high behind them. Furthermore, all these glaciers have advanced into Foreland Sound and have been cliffed by the sea. Small icebergs are occasionally discharged from their sea fronts. These facts show that piedmont glaciers are not necessarily characterised by predominant wastage, as indicated in Priestley's classification (p. 5).

Reticular Glaciers.—The type of glacier described in this section represents an approach to a middle stage in the deglaciation of a region of high relief. The ice occupies the whole

Digitized by Google

of the valley systems of the region, filling them to at least half their depths. The ice surfaces rise higher towards the valley heads, and sink near their debouchment towards sea level. Adjacent valley systems are joined up by ice masses passing over the cols (Hobbs' transection type); and the lower parts of the bounding ridges, especially towards the higher interior, are often covered with ice. The plan of such a glacier system thus shows an intricate network of ice covering the country, a feature beautifully illustrated in Isachsen's map of the north-western mountains (1915), and in some of his magnificent panoramas (1912, Pls. IV., VI., and VII.; 1915, Pl. III.). In this connection Prof. E. J. Garwood's fine panorama of the Kings Bay glacier system should be seen (1899, Pl. XLII.), also those of Holtedahl (*op. cit. supra*, Pls. VII. and VIII.), and of Hoel (1914, Pls. XV., XVI., and XVII.) of views in the north-western mountain region. . The writer provisionally called this type confluent glaciers (1921, p. 238), but this term has been pre-occupied (Wordie, 1921, p. 39).

Drygalski remarks the great development of "valley glaciers" in Spitsbergen, comprising the ice form known as "inland ice" (1911, p. 24). These glaciers are so powerfully nourished that they fill up their valleys and overflow gaps and watersheds into adjoining valleys (*e.g.* Monaco and Three Crowns Glaciers). Drygalski speaks of these forms as glacier networks (Eisstromnetz), a connected system of large valley glaciers. Garwood and Gregory (1898, p. 198) use the term "confluent series of glaciers" forming the so-called inland ice sheets, and instance the example on the north side of Ice Fiord.

A very large part of Spitsbergen is covered by this type of glacier system. It is prevalent in the western mountains from end to end. It also appears to be the predominant type in the eastern central parts of the country (Tyrrell, 1921, p. 238). Reticular glacier systems are well seen in the view north and north-west from the summit of Mt. Keilhau (Pl. I., Fig. 1); in the view west and south from the heights behind Whales Bay (Pl. XIII., Fig. 1), in which the Strong Glacier forms the main trunk of the system; and in the view west and south from the summit of Rurik's Forberg, in which the Inglefield Glacier

Digitized by Google

is the main stream. All these localities are on the eastern (Stor Fiord) coast of Spitsbergen. The writer believes that a more thorough survey would show that the whole of the region between Cape Dufferin and South Cape is occupied by only three or four reticular glacier systems. From its wide distribution this type, if any, is best entitled to be regarded as the distinctive Spitsbergen type of glaciation.

Dendritic Glaciers.—The term *dendritic* appears to apply to a system of glaciers occupying a single self-contained river valley and its tributaries.[7] The only possible example that came under the notice of the writer in Spitsbergen was the Hörbye Glacier, at the head of Petunia Bay, the northern branch of Klaas Billen Bay. The Hörbye Glacier occupies a long, straight highway stretching north-west, the ice passing over a divide distant about 10 miles from the termination of the glacier. Tributaries from the adjacent mountain region join the trunk stream on both sides down to its termination. Drygalski (1911, p. 28) counted four tributaries on each side (Pl. II., Fig. 1). The map of this glacier system would in all probability show the dendritic pattern which led Hobbs to assign this name to the group.

It is possible that dendritic glaciers are best developed in young mountain ranges, such as the Himalayas, whence Hobbs drew his typical examples. In these regions the individual valley systems are separated by high mountains, and steep, relatively ice-free rock barriers. In Spitsbergen the cols connecting adjacent valley systems are often so low that the separate systems are not well individualised; and consequently a comparatively small ice filling may pass over the barriers, and join up adjacent glaciers into a reticular ice mass. Dendritic glaciers are formed where the individual valley systems are well isolated.

Hobbs' type of *transection glacier* should probably be grouped along with reticular and dendritic glaciers, as it appears to represent the connecting masses of ice on cols between adjacent systems. But any type of large ice mass may pass over a col, and send down a stream in the opposite direction. Thus the best example of a transection glacier that came under the writer's notice in Spitsbergen was the ice mass whence the Miller

[7] Characteristics of Existing Glaciers, 1911, p. 47.

Digitized by Google

Glacier in Prince Charles Foreland proceeds. This is connected over a col 1400 feet above sea level with the Monaco piedmont glacier (Fig. 1B, text).

Valley Glaciers.—Valley glaciers are typically streams of ice occupying a single trough or valley, receiving no tributaries except near their heads, although they may receive contributions from niche, cascade, or avalanche glaciers on the valley walls. Valley glaciers may proceed from any of the larger ice masses before mentioned; but typically they originate in cirques, or systems of cirques, at the head of the valley. When a valley glacier has retreated almost or quite into its parent cirque, so that all that is left is a sheaf of small ice masses side by side, or radiating from a central point, with perhaps a small outflow tongue, we have then the radiating or Alpine type of Hobbs.

Drygalski (1911, p. 23) recognises that valley glaciers may be derived from different collecting grounds. Sometimes they originate in complexes of hollows, corries, &c., as in the Alps, and other mountains; other types proceed from "highland ice caps," such as those of Norway. Again they may be nourished by the accumulation of snow within the valley trough itself. He remarks that the Alpine type of collecting ground prevails in the Hecla Hook mountains of Spitsbergen, while the Norwegian form occurs mostly in the plateau regions.

Valley glaciers of all types are extremely numerous in Spitsbergen. Some of them will be mentioned later when special features are being described.

Expanded-foot Glaciers, in the writer's opinion, are merely variations of valley glaciers due directly to release of the ice from a restricted channel, the opportunity being afforded by the topographic accident of a widening of the valley, or to its debouchment on to an open space, whether that be a wider trunk valley, a raised marine platform, or an elevated plateau.

One type of expanded-foot glacier is exemplified by the Ebba and Ragnar Glaciers in the De Geer Mountains at the head of Klaas Billen Bay (Pl. IV., Fig. 2; see also Tyrrell, 1922, Pl. I., Fig. 1). In both of these valley glacier outlets of the New Friesland highland ice, the termination comes just below a constriction in the valley due to a hard Urgebirge outcrop. The lower part of the valley is excavated in the Carboniferous

Digitized by Google

outcrop, and is much wider than that cut in the Urgebirge. Hence on entering the wider portion the ice spreads like an outstretched feline paw, giving a typical expanded-foot effect.

Another type in which the catspaw effect is enhanced by radiating longitudinal crevasses is exemplified by a small glacier which enters Gips Valley from a tributary on the eastern side. The ice, freed from the restrictive effect of the narrow side valley, expands and terminates where it enters the main valley. A more advanced example of the same type is afforded by the famous Ivory Glacier, described by Garwood and Gregory (1898, map, p. 201), and studied again by Mr. A. Stevens in 1919 (Wordie, 1921, p. 40). In this glacier, the ice, emerging from a side valley, has pushed right across the main Fulmar Valley, and has impinged on the opposite side, resulting in a marked lateral expansion at its termination.

Doubtless examples of expanded-foot glaciers on a raised marine platform, or a plateau, are present in Spitsbergen, although examples did not come under the notice of the writer.

The *inherited basin* type of Hobbs[8] appears to be a glacier form determined by its location in a ready-made depression or trough of more irregular form than a river valley. His *cauldron glacier*, an ice mass collected in a well-preserved or partially-ruined crater, belongs to the same group. A very fine Arctic example of the latter has recently been described by J. M. Wordie from the crater of Beerenberg in Jan Mayen.[9]

Niche Glaciers.—The term niche glacier may be used to indicate all small ice masses collected in hollows on valley or plateau walls, or at valley heads. The term *horseshoe glacier* has been used by Hobbs for the dwindling remnants of valley or radiating glaciers clustered round the walls of the headward cirque. Excellent small examples of this type are to be found in the Macleod and Wotherspoon Corries (Pl. III., Fig. 2) of the Campbell Range on the east side of Klaas Billen Bay, between Adolf Bay and Ekholm Valley.[10]

The semi-circular head of the Macleod Corrie is divided into

[8] Characteristics of Existing Glaciers, 1911, p. 50.

[9] *Geogr. Journ.*, March, 1922, pp. 188-9.

[10] For place names in the Klaas Billen Bay region see the map by Mr. J. Mathieson in R. N. R. Brown's "Recent Developments in Spitsbergen." *Scott. Geogr. Mag.*, 1920, 36, p. 116.

Digitized by Google

two by a nearly central bluff (Pl. III., Fig. 2, left hand side; and Fig. 2A, text). A small ice mass occupies each depression. These are the only remnants of a glacier which once filled the corrie and sent a tongue down the valley towards Klaas Billen Bay. The glacier in the southern depression (visible in the photograph) is situated on a sloping ledge some hundreds of feet above the floor of the corrie. The ice face is vertical, with a height estimated at 100 feet. The basal part is finely stratified with rock debris, and there are also a few bands of debris in the upper layers, which show much contor-

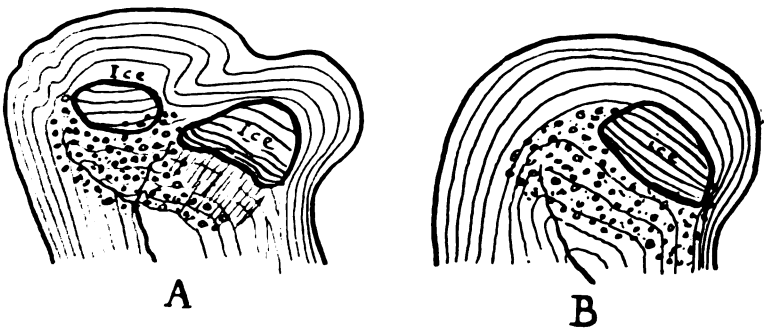


Fig. 2.—Horseshoe glaciers in MacLeod (A) and Wotherspoon (B) Corries, Campbell range, east side of Klaas Billen Bay. Morainic accumulations are represented by stippled areas (see p. 23). Scale about 1-inch to a mile.

tion and even overfolding. The steep slope in front of the glacier is littered with great blocks of ice which have fallen from its front. The glacier in the northern half of the corrie is almost smothered by a huge accumulation of moraine which forms hilly masses rising to a height of 1050 feet above sea level and 500 feet above the floor of the corrie.

The Wotherspoon Corrie is almost semi-circular, and is cut in nearly vertical cliffs of gypsum and Upper Carboniferous Limestone. Here again the remnant ice mass is accompanied by great moraine heaps rising to about half the height of the cliffs, that is, to about 1000 feet above sea level (Pl. III., Fig. 2, right hand side).

Ice masses completely covering the floors of semi-circular, armchair-shaped depressions on the sides or heads of valleys, and often in the walls of plateaux, are regarded as typical corrie or cwm glaciers, of which there are many beautiful examples

Digitized by Google

in Spitsbergen. The example figured (Pl. III., Fig. 1) occurs in a hollow on the south side of the Carron Glacier valley, near Adolf Bay.

Another small ice form, characteristically developed in hollows, niches, and gullies, is snowdrift ice. According to Philipp (1914, p. 23) this kind of glaciation (*Wachten*) reaches a considerable significance in Spitsbergen, and is favoured by the morphology of the country. Niches and gullies occur in profusion on the upper slopes of the plateau edges, and provide the best conditions for a permanency of snowdrifts, which are often strung together in a regular pattern (Pl. XI., Fig. 1). Occasionally the drifts of adjacent niches coalesce and form a surround to the plateau summit, a feature exceptionally well illustrated in Pl. XI., Fig. 1. Some of the gully feeders of the corrie glacier shown in Pl. III., Fig. 1, are probably of snowdrift origin, due to the influx of snow driven over the plateau edge by easterly winds. A similar origin may be ascribed to the small ice mass resting in a shallow hollow near the summit of the western slopes of Mt. Tyrrell, south side of Ekholm Valley, Klaas Billen Bay. Here the snow brought by easterly storms drives over the divide between two of the summits of the mountain, and is caught in the hollow beyond. The drifts here remain thick until the late summer, when the ice mass beneath becomes exposed.

The *Cascade Glaciers* (*Stufenvereisung* of Drygalski, 1911, pp. 18-9) appear to belong to the group of niche glaciers. Drygalski defines them as ice slopes which are held in "staircase forms" of the valley or plateau walls, the steps in the staircase presumably corresponding to ledges worn back on the softer strata. This ice form is characteristic of the walls of the sandstone plateaux of Nordenskiöld Land on the south side of Ice Fiord. In Green Bay, according to Drygalski, single ice slopes hang down and connect up with valley glaciers below, but are not united to the plateau ice above.

This ice form seems to be characteristic of cliffs of horizontal or nearly horizontal strata in which the beds are of varying hardness. Two excellent examples of cascade glaciers, descending from Mt. Robert, are feeders of the Carron Glacier, Adolf Bay (Pl. IV., Fig. 1). In the example on the left hand side of the photograph an expansion of the ice is to be seen half-way

Digitized by Google

down, on a ledge which has been excavated in a weak member of the horizontal beds of the Cyathophyllum Limestone Series (Upper Carboniferous). This relatively soft, shaly stratum can be clearly distinguished from the harder scarp-forming limestones above and below.

Incidence of Glaciation in Spitsbergen in Relation to Meteorology and Topography.

One of the puzzles of Spitsbergen glaciology is the occurrence of relatively ice-free areas in situations where there is no apparent relation to differences of climate or topography. Thus Bunsow Land, between Klaas Billen Bay and Temple Bay, has large valleys (*e.g.*, Gips Valley, Ekholm Valley, &c.) in which there are glaciers only near the heads. It is surrounded by heavily glaciated areas in New Friesland, Sabine Land, and Conway Land. A similar region is that to the south of Ice Fiord, Nordenskiöld Land, in which the broad, open valleys are free from ice, except where they join the uplands to the south. To the west, south, and east of this area the country is heavily glaciated. There are no very essential differences of topography, or height above sea level, or adjacence to the ocean, between the non-glaciated and glaciated regions.

Drygalski (1911, p. 21) emphasises the influence of wind and the relative abundance of sheltered places on the accumulation of snow and the incidence of glaciation. He points out that the Urgebirge terrains in Spitsbergen are less cleft and hollowed than those belonging to the Hecla Hook outcrops, and hence less ice and snow-covered. Furthermore, western slopes are less glaciated than eastern, because the prevalence of westerly winds, especially in the neighbourhood of the western Arctic ocean, makes the deposition of snow more difficult.

This point is illustrated by the relative freedom from ice of the north-western islands and coasts. The Hecla Hook regions of the west coast generally, with their intricately cleft and hollowed surfaces, make ideal collecting grounds for snow and ice, and therefore, on the whole, are heavily glaciated. On the east side of Wijde Bay the Urgebirge mountains are relatively ice-free, while the Hecla Hook terrain farther east is heavily glaciated.

The west side of Prince Charles Foreland is almost free from

Digitized by Google

glaciers, only three ice streams protruding their terminations beyond the mountain wall on to the raised marine platform. The east side, however, is very heavily glaciated, the raised marine platform being largely covered with the four piedmonts described in a previous section. The contrast is doubtless due to the influence of the westerly winds, which expend their warmth on the western slopes, and also hinder the lodgment of snow by their velocity, except in sheltered places. Hence most of the snow precipitation takes place on the eastern side of the mountain backbone of the island (Wordie, 1921, p. 26; Tyrrell, 1921, pp. 227-31). Further south, on the great Foreland Plain, nowhere more than 60 feet above sea level, and almost perfectly smooth, there is no possibility of the permanent lodgment of snow, and therefore no accumulation of ice.

Drygalski (1921, p. 21) further shows that when the prevalent wind is easterly, as in Virgo Bay, glaciation fails on eastern slopes; or again, if a westerly site be well sheltered, as in Magdalena Bay, then glaciation may be heavy.

Drygalski's explanation, however, does not seem to throw any light upon the question why Dickson Land and Bünsow Land, on the north side of Ice Fiord, and Nordenskiöld Land on the south side, should be relatively ice-free; whilst the more or less similar adjacent areas of Oscar II. Land, and those regions to the north-east, east, and south, should be so heavily glaciated. In this contrast a climatic difference is probably operative. It is well known that climatic conditions become more severe towards the east, and this may partly account for the heavy eastern ice sheets. There is probably also a difference in precipitation in the contrasted areas. As Lamplugh (1911, p. 220) and others have pointed out, precipitation is very small on the whole in Spitsbergen, and the present climate is cold enough to foster a vast extension of the present ice fields should the winter precipitation become heavier. The variations in the amount of ice in neighbouring regions are perhaps to be correlated with variations in precipitation and in mean annual temperature, but the meteorological data on which alone an attempt at solving the problem of the incidence of glaciation in Spitsbergen can be based, are quite wanting. De Geer (1910, p. 13) hints that the direct condensation of rime from fogs may be of importance in the accumulation of

Digitized by Google

ice. He remarks that "as to the glaciation . . . this is in Central Spitsbergen more reduced than in other tracts of the land, where sunny days are rarer, and the fog often dominates." However, the relatively ice-free country seems to have its full share of mist. The members of Sir Martin Conway's expedition of 1896, in the ice-free region of the Sassen Valley, were often exasperated to see the sun shining brilliantly on the great glaciers north of the Ice Fiord whenever the fog in which they were enveloped lifted slightly.

Advance and Recession of Spitsbergen Glaciers.

The oscillatory movements of certain Spitsbergen glaciers, their alternate advances and retreats, have recently been closely discussed, especially in regard to the well-known cases of the Sefström and Wahlenberg Glaciers on the north side of Ice Fiord (G. de Geer, 1910, pp. 16-20; G. W. Lamplugh, 1911).

Hoel (1911, p. 253) states that all glaciers in north-west Spitsbergen were then in retreat, whether terminating on land or in the sea. Those terminating in the sea were nearly devoid of crevasses and were fronted by partially drowned moraines, forming crescentic lagoons in which fragments of dead ice were lying. High moraines rose in front of the glaciers terminating on land, and their borders were covered with debris. Owing to this protective covering the peripheral zones showed marked convexities. Hoel (1914, p. 62) gives details of advance and retreat for several of the north-western glaciers, and states that, on the whole, the nineteenth century was a period of general retreat.

Drygalski (1911, p. 44) states that Spitsbergen glaciers are at present predominantly in retreat. They have heavy moraines on their margins, or somewhat in front of their terminations. This enrichment in surface debris is due to the supply of ice not keeping pace with the wastage, thus bringing intraglacial material to the surface. Garwood and Gregory (1898, p. 207) noted a marked depression in the middle of the upper part of the Booming Glacier, which they attributed to shrinkage due to diminished snowfall near its head. Since at that time the Booming Glacier had a Chinese-wall termination (p. 31), the wave of recession had evidently not reached its lower end.

Digitized by Google

Philipp (1914, p. 44) cites a striking case of recession in one of the southern side tributaries of the Von Post Glacier. In this valley the glacier had so receded that it had ceased to be a tributary to the trunk stream, in which, however, it had left a lateral mass of dead ice, strikingly inert compared with the main stream. A medial moraine derived from the next higher side glacier formed a boundary between the dead ice and the moving main ice stream. The space between the present termination of the side glacier in question and the lateral moraine of the Von Post Glacier was filled by a glacial lake, the shores of which were terraced.

Some of the glaciers in the Stor Fiord region are reaching or have only recently passed a stage of maximum advance (Wordie, 1921, p. 42; Tyrrell, 1921, p. 238, 240). The Strong Glacier (Pl. XIII., Figs. 1 and 2), descending into Whales Bay, has recently been advancing as its lower part is heavily crevassed, and it has built a long black bank of lateral moraine a mile or two out into the sea on its northern side. The termination of the Hayes Glacier now occupies most of the northern half of Mohn Bay. It is thrust out as a broad tongue of ice extending 3 to 4 kms. beyond the coast line, and unequally bisecting the bay (see Philipp, 1914, Pl. IV., Fig. 2). This is shown in Filchner's map of 1914. Older maps, such as Heuglin's,[11] show Mohn Bay unbroken by the glacier, which is mapped as not extending beyond the coast line. Hence the Hayes Glacier must have made a great advance in the last thirty to forty years (Philipp, 1914, p. 44). At present (1920) it appears to be retreating, as tabular islands of glacier ice are to be seen resting on the shallow sea floor in front of its termination (Pl. VII., Fig. 1, background).

The southern part of the Mohn Bay region is occupied by a large glacier (Usher Glacier), which does not reach the coast line (Pl. VII., Fig. 1). In contrast to the adjacent Hayes Glacier, from which it is separated by the Krogh Berg, it has been retreating for some time, as shown by the fact that its termination is surrounded by a huge, semi-circular moraine, which in places is a quarter of a mile broad, and shows a characteristic knob and basin topography. It rises well above the

[11] Reisen nach dem Nordpolarmeer, 1872.

Digitized by Google

depressed peripheral surface of the ice. Between the terminal moraine and the sea is a boggy outwash plain.

The Negri Glacier must have advanced considerably within the last 200 years, for the Edlundberg and other mountains now surrounded by the ice were not so in the seventeenth century. Walrus and Robben nunataks were also indicated on the old maps as islands (Philipp, 1914, p. 44).

One of the most striking cases of recent advance is that of the Duckwitz Glacier,[12] which descends to the sea at about the middle of the western coast of Barents Island, just opposite the Anderson Islands. This glacier is obviously in a phase of violent advance (Pl. VII., Fig. 2). Its skyline profile is extraordinarily jagged and serrated owing to the abundance of great crevasses and seracs, notwithstanding that the gradient of the valley and the adjacent sea floor is very gentle. The ice is dark all through owing to the immense quantity of mud and fine debris from the soft Mesozoic shales which has been incorporated. On the southern margin of the glacier there is tremendous folding, crumpling, and contortion of the stratification planes of the ice. The glacier now projects about three miles beyond the coast line, forming a broad tongue resting on the shallow sea floor. In its impetuous advance it has overwhelmed the low-lying Anderson Islands, which are mapped as occurring immediately in front of it. These islands were accessible at the time of the Russo-Swedish surveys of 1898-1902, and were geologically described by V. Carlheim-Gyllenskjöld. It is stated that the Russians were astonished at the rich vegetation covering the islands (Sir Martin Conway, 1903). Now, however, only small portions of them are to be seen emerging from beneath glacier ice. Hence the great advance of the Duckwitz Glacier must have taken place within the last twenty years.

Some evidence is brought forward on p. 18 to show that the piedmont glaciers of Prince Charles Foreland are on the whole slowly accumulating and advancing. There has certainly been a slight recession of the northern front of the James Geikie Glacier, as indicated by a line of old lateral moraine.

[12] Called the Gregory Glacier in Wordie, 1921, p. 42, and in Tyrrell, 1921, p. 240. The name Duckwitz Glacier has priority as it appears on Heuglin's map (1872).

Digitized by Google

The Alfred and Magda Glaciers,[13] however, situated side by side in the region between the Buchanan piedmont glacier and Ferrier Haven, and originating in the great corries of the Thomson Hills, show contrasted features. Both are comparatively steep-fronted, although the termination are not Chinese walls. The Alfred Glacier is certainly in retreat, as it has left in front of it an ancient, vegetation-covered moraine; the Magda Glacier, on the other hand, appears to be active, and its front is trespassing on the mud of the Marchais Lagoon.

The broad, elevated marine platform on the west side of Prince Charles Foreland shows little sign of ever having been largely covered by piedmont ice (for fine illustration of the west coast platform see R. N. Rudmose Brown, *Spitsbergen*, 1920, Pl. facing p. 192). There is, however, a large lateral moraine running north and south on the Traquair Beach at the western foot of Mt. Monaco, indicating the former presence of a piedmont lobe, or more probably the expanded foot of the small moribund glacier now occupying the corrie between Mt. Monaco and Mt. Rudmose.

At present only three valley glaciers protrude their terminations beyond the mountain wall on to the western marine platform. The one descending from the south flank of Mt. Parnassus has a very steep gradient, and shows huge crevasses and seracs at the head of its ice fall. It has pushed out on to the Traquair Beach, and carries a heavy moraine which it overtops. This glacier is clearly in a phase of rapid advance. Another glacier emerges from the valley between Mt. Parnassus and Mt. Phipps, and projects a long flat lobe on to the Traquair Beach. It carries a heavy moraine, but its front is now flat and depressed below the moraine, so that it is quiescent or retreating after a period of advance.

The Miller Glacier also projects on to the western marine platform from the valley descending from Mt. Bourrée. It appears to have been practically stationary for some years; at all events its appearance in 1919 differed very little from that presented in Hoel's beautiful photograph of date 31st July, 1907 (Hoel, 1914, Pl. VIII., Fig. 2).

The causes of the oscillations of Spitsbergen glaciers, and of

[13]For localities in Prince Charles Foreland see the maps in Tyrrell, 1921, and Wordie, 1921.

Digitized by Google

the frequent cases of alternate advance and retreat of neighbouring glaciers, have been little investigated; and indeed very few of the essential data for the solution of the problem have yet been collected. Climatic variations, as suggested by several authors, may be the principal cause of the major oscillations. For the recent advance of the glaciers on the western side of Prince Charles Foreland, Wordie (1921, p. 42) suggests exceptional nourishment by avalanches, which explanation is also suggested by Drygalski for similar phenomena in certain Greenland glaciers (1911, p. 45). Lamplugh (1911, p. 221) cites de Geer's personal explanation of the advance and retreat of certain Spitsbergen glaciers, and the opposed movements of such paired glaciers as the Sefström and the Wahlenberg. When the gradient of the glacier is gentle the snowfall is inadequate to maintain a constant flow, so that the accumulations of several years may be necessary to overcome inertia, and cause a wave of forward movement to pass down the glacier. When the limit is overpassed, a phase of active advance ensues, which lasts until the accumulated ice is all discharged and a state of quiescence again reached. The periods of advance and retreat in neighbouring glaciers are unlikely to be synchronous because of the probable differences in length, gradient, and snow precipitation.

Some of the criteria of advance and retreat have been incidentally mentioned above. The inclination of the ice front appears also sometimes to be a valuable criterion in the case of glaciers terminating on land. A steep or vertical (Chinese wall) front seems to indicate advance, whilst a gently tapering front indicates a still-stand or retreat. Garwood and Gregory in 1896 found that the majority of the glaciers met with possessed a Chinese-wall front, but the writer in 1919 and 1920 did not see a single vertical front in glaciers ending on land (see also Wordie, 1921, p. 39). Tide-water glaciers, such as the Nordenskiöld Glacier (Pl. I., Fig. 2; Pl. XII., Fig. 2) certainly have vertical, cliff-like terminations, but these are due to erosion and undercutting by the sea. All the glacier terminations on land seen by the writer in 1919 and 1920 were tapering, but the angles of inclination of the fronts differed considerably in individual cases. Thus the northern front of the Monaco (Murray) piedmont glacier in Prince Charles Fore-

Digitized by Google

land had a slope of 8 degrees. The fronts of the Ragnar and Ebba Glaciers (Pl. IV., Fig. 2; and Tyrrell, 1922, Pl. I., Fig. 1) have not much greater inclination than this. The average slope of the front of the Pollock Glacier (Pl. VI., Fig. 2) is about 15 degrees. The greatest inclination seen was in the front of the Carron Glacier, near Adolf Bay, which, in places, terminated in a slope approaching 60 degrees. The Fairweather Glacier, in a valley debouching in the Ekholm Valley east of Mt. Tyrrell, shows a similar steep front, down which there is a continual fusillade of stones from the terminal moraine.

It may be concluded that the prevalence of gently sloping terminations is to be correlated with the present general retreat of Spitsbergen glaciers attested by many authors; and that the Chinese-wall terminations so prominent towards the close of the nineteenth century indicated a general forward movement at that time.

Some Surface Features of Spitsbergen Glaciers.

Moraines.—Very abundant intraglacial material is characteristic of many Spitsbergen glaciers (Cole, 1911, pp. 200-1), especially those whose courses traverse the soft Mesozoic and Tertiary rocks building the plateaux of the central and eastern parts of the country. A good example is the Duckwitz Glacier in Barents Island (p. 29), the ice of which is dark all through owing to the immense amount of mud and fine dirt it has picked up. Even in the Carboniferous country of Klaas Billen Bay, some of the glaciers (*e.g.*, Carron Glacier, Adolf Bay) are banded from top to bottom with intraglacial material. On such glaciers, however, blocky surface morainic material is often comparatively scanty. This is due partly to the lack of hard rock, and partly to the relative scarcity of extensive cliffs above the ice, especially in the headward parts of the glaciers. The frequent abundance of boulders on the terminal moraines may be partly due, as Cole believes (1911, p. 200), to plucking from the frost-disintegrated floors of the glaciers. The great quantity of fine muddy intraglacial material has a considerable bearing on the origin of boulder clay, which is dealt with later on (p. 35).

The moraines of the Nordenskiöld Glacier have been fully

Digitized by Google

described in another place (Tyrrell, 1922, pp. 217-18). The investigation of their composition has been found extremely useful in determining the geology of the rock floor of the glacier and of other inaccessible regions. An interesting point arises in connection with the southern medial moraines of the Nordenskiöld Glacier. These originally joined up with the southern lateral moraine near the termination of the glacier; but a recent vigorous advance of the tributary glacier from the valley between Mt. Urmston and Mt. Cadell has thrust a tongue of relatively rapidly-moving ice into the southern lateral portion of the Nordenskiöld Glacier, causing the first five medial moraines to curve round like the end of a shepherd's crook before joining the lateral moraine (Pl. VII., Fig. 3). Ultimately the medial moraines may be quite broken through. G. de Geer noted this feature in his work of 1910 (p. 15, and map, Pl. III.).

Ablation Effects.—Fine ice-tables are abundant on the Nordenskiöld Glacier, one of which is illustrated in Pl. VIII., Fig. 1. The pedestals are invariably undercut on their southern sides owing to the greater amount of heat received on this side. When the boulder caps slip off they always fall to the south (see distant boulders in Pl. VIII., Fig. 1). The phenomenon of honeycombing due to dust wells can be seen in the foreground of the same view. Very symmetrical dirt-cones also occur on the Nordenskiöld Glacier (Pl. VIII., Fig. 2). The origin of some of these accumulations was suggested by the occurrence of abandoned stream channels on the ice. In the wider parts of these gullies, or on the inner sides of curves, there is often a deposit of mud or fine grit, left stranded by the disappearance of the stream down a crevasse, or by diversion into another channel. On the general summer ablation of the surface these masses of mud protect the ice beneath, and in course of time cause it to project above the general level.

The thin southern medial moraines of the Nordenskiöld Glacier protect the ice beneath in exactly the same way. These moraines appear to rise from 10 to 20 feet above the general level of the ice; but the veneer of blocks and gravel is very thin, and the rise is really due to a long ridge of ice which has been protected from melting by the moraine. Hoel

Digitized by Google

(1911, p. 253) shows that the receding glaciers in N.-W. Spitsbergen have borders covered with debris, and these peripheral zones, thanks to the protective covering, exhibit marked convexities.

Drainage Effects.—Garwood and Gregory (1898, p. 211) found Spitsbergen glaciers intersected by river channels often deep enough to be impassable by sledges. Garwood (1899, p. 685) mentions the waterlogged slush covering glacier surfaces in early summer. This collects in hollows of the surfaces, forming lakes, which are ultimately discharged when the drainage gathers into a regular river system. This covering of waterlogged slush is a characteristic feature of the flat piedmont lobes of Prince Charles Foreland. Excellent examples of stream channels were noted on the Nordenskiöld Glacier (Pl. VIII., Fig. 1), and on many other Spitsbergen glaciers.

Fountains are a common feature on Spitsbergen glaciers. The Carron Glacier (Adolf Bay) shows several; one, almost on the edge of the cliff-like termination of the glacier, spouts about three feet into the air. The water disappears down a fissure, to emerge again from a tunnel on the face of the glacier, forming a considerable waterfall in the thaw season (Pl. X., Fig. 1).

Movement Effects.—Besides the ever-present crevasses, seracs, ice-falls, &c., on Spitsbergen glaciers, effects ascribed to movement were observed on the Monaco (Murray) piedmont glacier in Prince Charles Foreland. Off the eastern face of Mt. Bourrée there is a huge basin-shaped depression in the ice, of semi-circular outline, the chord of the arc being the cliff face of the mountain. All the adjacent surface streams discharge into this hollow, the water disappearing down at least six moulins and tunnels. This depression is believed to be due to the presence of stagnant ice between the ice streams issuing from the valleys north and south of Mt. Bourrée. It may be regarded as an ice eddy between two parallel moving streams feeding the piedmont lobe.

Garwood (1899, p. 683) mentions compression and surface swelling of glacier ice on the impact face of a nunatak. Marginal crevasses were due to differential movement of ice towards the lee side. This is exactly the opposite effect to the hollow described above.

Digitized by Google

The Formation of Boulder Clay.

Most recent observers are agreed that materials indistinguishable from the lowland boulder clays of Britain are now being deposited, or have recently been deposited, by Spitsbergen glaciers. Garwood and Gregory (1898, p. 209) speak of square miles of country in front of the Booming Glacier being covered with material closely resembling boulder clay, and ascribe it to the deposition of intraglacial moraines on melting of the ice. Another outstanding example is that of the advance of the Sefström Glacier in Ekman Bay, graphically described by G. de Geer (1910, p. 16), whereby Cora Island was plastered with typical boulder clay, and its size doubled. Lamplugh (1911, pp. 221-36) has given the most circumstantial account of this occurrence. The material deposited was a red clay, with rather sparse boulders, but with multitudes of marine shells. The red clay was derived from the disintegration of the reddish Devonian marls and sandstones; the shells were dredged up from the shallow sea floor the advancing glacier had to traverse. Lamplugh estimates a vertical uplift of from 50 to 100 feet for this marine material, with a possible maximum of 250 feet. This agrees with the estimates of Garwood and Gregory (1898, pp. 205-6) for the uplift of shells by the Ivory Glacier, although the shells here were derived from raised beaches. The bearing of these observations on the possible mode of transport of shells in British boulder clays is obvious.

Lamplugh (1911, p. 229) states that the material deposited on Cora Island had almost exactly the appearance of a boulder clay of the Yorkshire or Lancashire coast. He notes (p. 237) that the boulder clay deposited by the Von Post Glacier was a grey stony clay very like that of N.-E. England. It contained numerous boulders highly worn and glaciated, but no shells. Like that of the Booming Glacier, this boulder clay was doubtless deposited on land well above sea level.

Boulder clay deposited by the Nordenskiöld Glacier is also mentioned by Lamplugh (1911, p. 236). He remarks that the glacier has incorporated some of the shelly raised beach material near its margins, and thus a few, dispersed, broken shells are to be found in its boulder clay. These observations

Digitized by Google

were confirmed by the writer for localities near the glacier; but boulder clay with a few contained shells was also observed at several places along the eastern shore of Klaas Billen Bay, underlying the raised beaches. This is well exposed along the stretch of coast immediately south of Ekholm Valley (Pl. VI., Fig. 1). The boulder clay is quite typical, grey, unstratified material with fairly numerous boulders and a few broken shells. Twenty to thirty feet of thickness is visible, and the upper part is seen to have been worked over and redeposited to form part of the material of the lowermost raised beach. Another point noted by Lamplugh in the von Post Glacier was the upturning of the stratification planes of the ice, by which different materials, the red "Archæan" moraine and the grey Car-

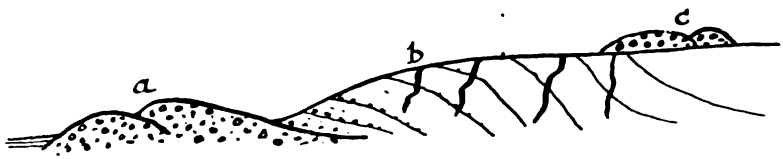


Fig. 3.—Section at south-west corner of the Nordenskiöld Glacier, near the mouth of Gerrit River—*a*, ground moraine; *b*, dark stratified ice bringing up intraglacial and ground moraine to the surface; *c*, medial moraine discharging over side of glacier (see p. 36).

boniferous moraine, were brought up. On melting of the ice interstratification of different kinds of boulder clay would arise. Hence this phenomenon is no sure indication of separate periods of glaciation (1911, p. 238).

In the same way the writer has noted the marked differences between the several medial moraines of the Nordenskiöld Glacier, and between these medial moraines as a whole and the terminal ground moraine (Tyrrell, 1922, pp. 217-8). On melting of the Nordenskiöld Glacier interstratification of distinctly different boulder clays would ensue, as well as lateral heterogeneity in the same horizon. The section (Fig. 3, text) illustrates how the morainic materials of the Nordenskiöld Glacier are kept separate. The surficial moraines are derived from distant nunataks consisting of Carboniferous rocks resting on a basement of the Hecla Hook System, which is intruded by a syenitic suite of igneous rocks. The terminal moraine on the other hand is derived from the rock floor near the ter-

Digitized by Google

mination of the glacier, and consists mainly of metamorphic rocks.

The Arctic tundras, with their abundant plants and remains of reindeer, bear, fox, and occasionally whales,[14] often extend right up to the terminations of the glaciers; and when near the coast they may cover some of the older raised beaches. An oscillation of a glacier front, therefore, may cause this varied material to be buried under a plaster of boulder clay, giving rise to a deposit which might later be interpreted as interglacial, and as denoting a relatively mild interglacial epoch.

As several observers have noted, the conditions of Arctic weathering in a country such as Spitsbergen, consisting largely of soft and easily disintegrated stratified rocks, provide a great abundance of fine muddy and stony material ready to be converted into boulder clay. Everywhere there are mud-flows, rock-streams, landslides, alluvial deposits, talus fans, outwash plains, ready to be incorporated as the intraglacial material of an advancing glacier; and needing only the mixing, churning, and compacting effects of the ice in order to transform it into typical boulder clay. The abundance of shale and clay among the stratified rocks helps considerably in providing the clayey matrix. This material may be deposited indifferently on land, or in shallow marginal parts of straits, bays, or seas. In the latter case it may become intermingled with marine deposits. Marine organisms may also occur in boulder clay because sea floor deposits may have been dredged by the glacier in passing across a shallow arm of the sea (*e.g.*, Sefström Glacier), or through the incorporation of raised beach materials (*e.g.*, Ivory Glacier, Nordenskiöld Glacier).

The Earlier Glaciation.

There is little doubt but that the present glaciation of Spitsbergen is the remnant of a vastly greater glaciation which, during the Pleistocene Glacial Period, swathed the whole of the country under a mantle of ice probably of the dimensions of a continental glacier. Controversy now centres upon the extent of this earlier glaciation, and upon the question of

[14] J. Lamont, *Seasons with the Seahorses*, 1861, p. 200.

Digitized by Google

its continuity with the present. In their first paper Garwood and Gregory (1898, p. 197) accepted the sharp, serrated peaks and ridges at the entrance to Ice Fiord as evidence that Spitsbergen had not at any recent time been wholly submerged beneath an ice-cap. Garwood later, however (1899, p. 688), receded from this position, and stated that "the more the district is studied the more evident becomes the fact that denudation is proceeding with a rapidity difficult for those to realise who are only acquainted with weathering in a temperate climate; and I do not think that any argument can be drawn from the present angularity of the peaks above the snowline."

Several observers have noted the scarcity of the usual signs of former glaciation (*e.g.*, Lamplugh, 1911, p. 218); and have attributed the rarity of rounded summits, smoothed slopes, striated surfaces, erratics, &c., to the intensive Arctic weathering. Lamplugh noted that transported blocks were in some cases reduced to patches of frost-riven splinters. Especially, of course, is this the case with the softer, and also the harder, stratified rocks, when the latter are well jointed. The massive schists, gneisses, slates, quartzites, and igneous rocks of the Pre-Devonian are much less affected; and in the Klaas Billen Bay region have afforded particularly good indicators of the extent of former glaciation. The ease with which a soft rock succumbs to the attack of frost in an Arctic climate may be illustrated by the case of a peculiar isolated cone about 12 feet high, consisting of small gypsum fragments, which the writer found on the surface of the Pollock Glacier. This was clearly due to the disintegration by frost of a large, joint-bounded, cuboidal block of the Lower Gypsiferous Series.

The rapidity with which limestone pinnacles and ridges disintegrate under the attack of frost may be illustrated by reference to the many peculiar scenic effects of the mountain summits of the Klaas Billen Bay region (Tyrrell, 1921, p. 233, Figs. 2, 3). The summits and ridges, when composed of the hard Carboniferous limestones, are toothed, jagged, and serrated to a degree. It is only necessary for the geologist to climb up and under one of these ridges, and observe and dodge the continual rain of stones from them, for him to realise the intensity and rapidity of denudation under Arctic conditions. The Wordie Crags in the De Geer Mountains at the head of Klaas

Digitized by Google

Billen Bay may be taken as a typical example of this phenomenon (Pl. IX., Figs. 1, 2). The crags consist of a narrow, vertical-sided, elongated cake of hard, massive, bedded limestones, perched on the summit of a sharp arête built of the softer limestones, dolomites, and gypsums of the stratigraphical group underlying the Upper Carboniferous Limestone (Cyathophyllum Limestone) of the crag itself. The serrated aspect of this crest is well seen in the figures. The pinnacle (Pl. IX., Fig. 2) ("The Pin") at the western end of the Crags measures 3 feet by 1½ feet by 10 feet high. It forms an admirable trigonometrical station; but it is already shaky, and will not last for many more seasons. The valleys at the foot of the Wordie Crags on both sides contain huge boulders fallen from the limestone summit. The largest seen occurs in a valley on the south side of the ridge. It measures 54 feet by 42 feet by 30 feet, and is estimated to weigh 5000 tons. Another measured block was 24 feet by 28 feet by 22 feet.

The Wordie Crags, then, judged by the standards of temperate regions, are typically non-glaciated; yet at a height of 2145 feet, close to The Pin, there were found numerous boulders of hornblende-schist, the largest of which was 3 feet by 2 feet by 2 feet. The nearest exposures of hornblende-schist in this neighbourhood are in the valley on the north-west side of the Nordenskiöld Glacier, and in the Ebba Valley, each locality 3 miles distant from the western end of the Wordie Crags. It is hardly possible to avoid the conclusion that, during the period of maximum glaciation, the Wordie Crags were completely covered by ice; and that their present jagged outline is due to intensive frost weathering since the ice receded.

It is quite probable, however, that some of the peaks of the western Hecla Hook mountains, projected as nunataks through the marginal parts of the ice-cap, and may never have been entirely covered by ice. Drygalski (1911, p. 45) shows that the earlier glaciation must have been much heavier than the present; but because of differences in the form and weathering of the summits and lower ground, he does not believe that the ice enveloped all the heights of land. He holds that the peaks about Cross Bay and Kings Bay pro-

Digitized by Google

jected from the ice at its maximum extension, and that their weathering was pre-glacial.

Striated and grooved surfaces are comparatively scarce. They are found only on hard massive rocks that happen to be exposed near sea level, such as the dolerite of the Anser Islands at the mouth of Klaas Billen Bay; or on recently uncovered surfaces, as for example, a limestone surface at Cape Scott (Klaas Billen Bay) from which boulder clay is being stripped by the waves. The surfaces of the Anser Islands are beautifully moutonnéed, and show striæ and grooves roughly in the direction of Klaas Billen Bay. G. de Geer (1910, p. 20) mentions an older set of striæ running in the mean direction of the East Branch of Ice Fiord, which were scored by the ice mass due to the fusion of the Klaas Billen Bay Glacier with that proceeding from Sassen Bay. The younger set belongs to a later time when the two main branches of the East Branch Glacier had become isolated by recession. The striæ and grooves at Cape Scott, preserved under boulder clay, are in the direction of the coast line, and were evidently made by the former Klaas Billen Bay Glacier.

The remaining question as to whether there has been essential continuity between the Pleistocene and the present glaciation is now generally answered in the affirmative. The question is closely bound up with that of the fine series of raised beaches so prominent on the western coasts and the interior fiord shores. The evidence of the raised beaches proves that the land has stood at a level of at least 430 feet lower than at present since the period of maximum glacial extension, the highest beach recognised by G. de Geer, standing at that height above present sea level. Moreover, the presence of *Littorina rudis*, *Cyprina islandica*, and *Mytilus edulis*, in the lower beaches proves a somewhat milder climate than the present, since these species are not now living in Ice Fiord. But this evidence is wholly insufficient to prove the great break between the maximum glaciation and the present, that Philipp (1914, pp. 41-5) tries to show in his excellent essay on the relations between the past and present glaciations. By an inverted kind of reasoning he comes to the conclusion that a depression of from 130 to 150 metres has taken place in the interval, with the conversion of the main island into an archipelago; then an

Digitized by Google

uprise in stages resulting in the formation of the raised beaches. The depression of the land relative to the sea caused a rise of the snow line, and produced an amelioration of the climate, attested by the recession of the ice and the fauna of the raised beaches.

This reasoning, however, will not carry conviction if it is held that the depression of the land was caused by, and proceeded *pari passu* with, the gradual advance of glaciers over the region, culminating in the maximum glaciation. Assuming that there was a lag in the recovery of the depressed land surface, the sea would enter the portions below the then sea level only as the ice regressed in response to the oncoming milder climatic conditions. Continually relieved of more and more of its ice load, the land surface would rise spasmodically, intervals of rapid rise alternating with periods of still-stand, during which the main beaches would be formed. The intervals of rapid upward movement are attested by the frequent occurrence of series of crescentic storm beaches, each a few feet above the other, and often forming a connection between the main beach platforms. One of these series of storm beaches, connecting two main beaches, at Cape Ekholm (Klaas Billen Bay), is shown in Pl. XI., Fig. 2, mid-distance. There are also some very fine examples in Gips Bay, and at C. Bjona, Temple Bay (G. de Geer, 1910, Pl. 13B). In Gips Bay the successive strand lines show very perfect curves marked by vegetation in the hollows between the lines of shingle. They lead up to a well-marked level beach at about 150 feet above sea level. Further inland, both the upstream and downstream sides of the great terminal moraine of the bygone Gips Valley Glacier are fringed with a beautiful series of raised beaches from 280 feet above sea level downwards, the curved strand lines succeeding one another at intervals of a few feet, and broken in two places only by broad, flat beaches with steep edges, marking periods of still-stand during the uplift.

Wordie (1921, p. 43) mentions a beach at Adolf Bay rising from sea level to 50 feet above sea level in about half a mile, the surface of which is covered by a continuous series of concentric ridges each representing a storm beach, of which the lowest is the present-day storm beach. This fact clearly indicates that the uprise of the land is still proceeding.

Digitized by Google

The figures given by Wordie illustrate the tilting which is so prominent a feature of the raised beaches in the Klaas Billen Bay region. Successive beaches sink gradually to sea level on being traced to the north.

The rise of the beaches to the south may be exemplified by a beach situated about half a mile south of the Swedish hut in Ebba Valley. It is here about 80 feet above sea level, but in a quarter of a mile it rises gradually to a height of 120 feet, when it disappears under talus.

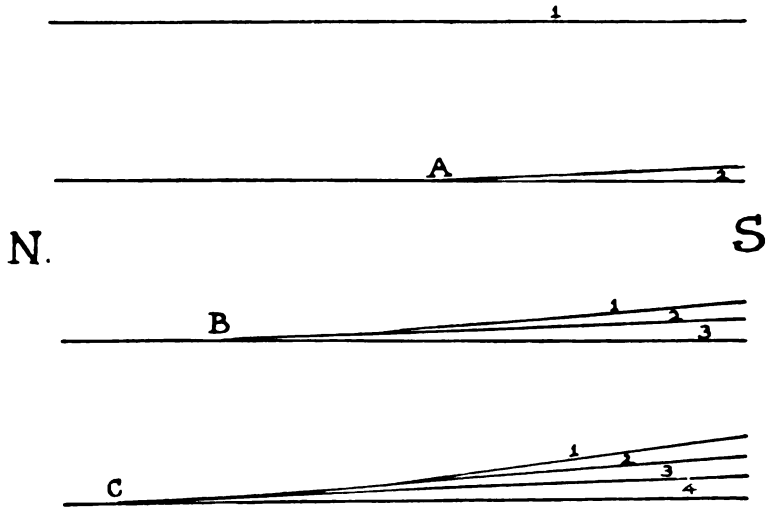


Fig. 4.—Diagram illustrating effects of the tilting of the land about hinge-lines shifting towards the north. The points A, B and C indicate successive positions of the hinge-line; 1, 2, 3 and 4 represent successive raised beaches (see p. 43).

A rise to the east may also be demonstrated in the Ekholm Valley. Fronting the Ekholm river delta there is a very well-marked raised beach at 160 feet above sea level. This beach may be traced up the Ekholm Valley, where it forms an excellent highway for journeys in that direction. At the bend in the valley to the north, about three miles from Klaas Billen Bay, the beach reaches a height of 275 feet above sea level (Pl. X., Fig. 2).

These facts indicate a tilting movement of the land about a hinge-line or hinge-lines probably running in an E.N.-E. to W.S.-W. direction in the region near the head of Klaas Billen

Digitized by Google

Bay. The probability is that there has been a succession of hinge-lines, each further to the N.-W., following the recession of the main ice mass. The diagram, Fig. 4, text, showing the succession of beaches following upon successive northward shifts of the hinge-line, illustrates this view, and represents in a diagrammatic manner the probable arrangement of the principal beaches on the eastern side of Klaas Billen Bay. The successive beaches are numbered 1, 2, 3, and 4.

Raised beaches and marine terraces appeared to the writer to be very much less conspicuous in the Stor Fiord region than on the west coast or in the interior fiords. On the north side of Agardh Bay there is a rock platform at 80 feet above sea level, which is covered in places by a thin discontinuous veneer of shingle. The inconspicuousness of raised beaches in this region may perhaps be correlated with its still heavy glaciation, the land not having yet been "let up."

Some Erosional Effects of Past and Present Glaciation.

Corries.—Many excellent examples of corrie or cwm formation in all stages may be studied in Spitsbergen. Cole (1911, p. 190) has especially emphasised the action of thaw water and repeated frost along the edges of snow patches and drifts, leading to rapid destruction of rock. This is the *nivation* process of Hobbs.[15] The snow patches eventually burrow down into the ground, leading finally to the accumulation of ice in the hollow, and the formation of a typical corrie or cirque (Pl. III., Figs. 1, 2). The formation of great semi-circular hollows in this way may be the cause of the enormous morainic accumulations that are to be found in some of the corries, *e.g.*, the Macleod and Wotherspoon Corries (p. 23), although some of this is certainly due to snow- and debris-avalanching down the steep encircling gullies (Cole, 1911, p. 193). Cole (1911, p. 196) further remarks the irregular and apparently accidental distribution of cirques on the edges and walls of plateaux. He compares the cirque hollows in all stages of formation to the results of the progress of some corrosive malady—the "cirque disease"—eating into the land. The point is excellently illustrated by his Pl. XI., Fig. 1, of the plateau of

[15] "Characteristics of Existing Glaciers," 1911, p. 18 *et seq.*

Digitized by Google

Dickson Land. The location of cirque hollows upon a ledge of weak rock has been referred to on p. 25 (Pl. IV., Fig. 1). Cole (1911, p. 198) points out that some hanging valleys may be due to cirque action, in which cutting-back into the margin of a plateau may progress faster than downward cutting. Pl. XI., Fig. 1 of this paper gives a good illustration of this effect.

Joint Control.—Pl. XI., Fig. 1, also illustrates the effect of the even and close spacing of joints in the horizontal Tertiary

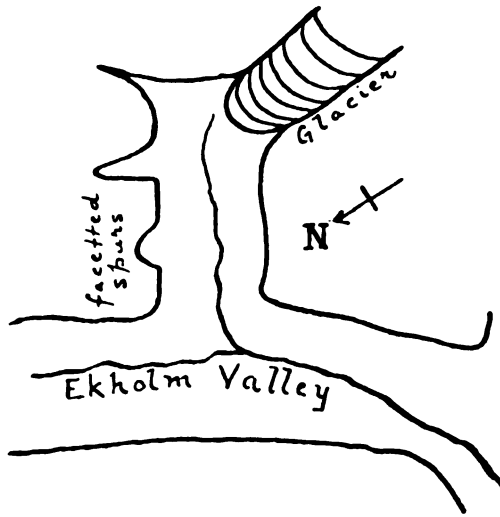


Fig. 5.—Plan of part of Ekholm Valley, showing facetted spurs in a tributary, probably due to impact of the glacier shown during a period of former extension (see p. 44) Scale about 1 inch to a mile.

rocks in controlling the distribution of gullies, snow-streaks, and the frilled edges of ice and snow overhanging the margins of the plateau.

Facetted Spurs.—The best example of facetted spurs seen by the author was in a tributary of the Ekholm Valley on its eastern side, about three miles east of the shore of Klaas Billen Bay (Pl. X., Fig. 2). Two great mountain spurs have been planed off, leaving huge symmetrical triangular facets. A glacier strikes obliquely down a valley in the south-eastern corner (not visible in the photograph) directly towards the facetted mountain side; and the pressure of this ice stream at the time

Digitized by Google

of maximum glaciation is believed to have been responsible for this erosive effect (Fig. V., text).

Overflow Channel in Sassen Valley.—The first tributary on the north-east side of the Sassen Valley occupies a fine V-shaped valley cut in the Permo-Carboniferous Productus Cherts and Limestones, which is buttressed like a miniature Colorado Canyon. The spur between this valley and the shore of Temple Bay is intersected by a deep trench with its main slope in the direction of the sea (Fig. VI., text). This is clearly a

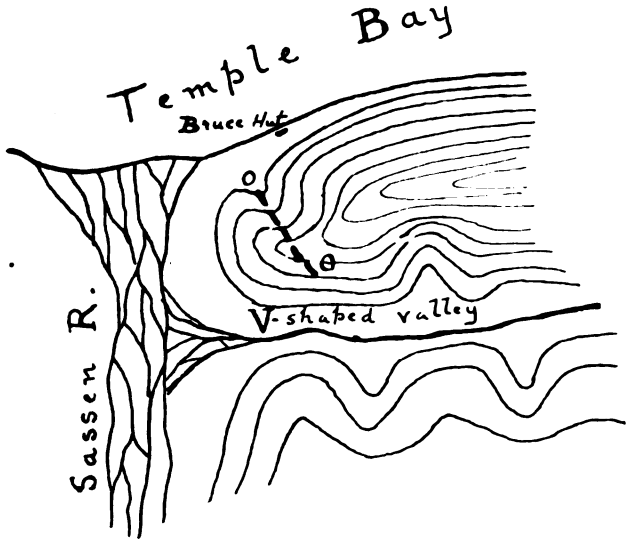


Fig. 6.—Sketch map of region at mouth of Sassen River, showing course (O—O) of a glacial overflow channel (see p. 45). Scale about 1 inch to a mile.

glacial overflow channel made when the Sassen Glacier filled the whole of its valley and blocked up the tributary, the glacier in which had retreated for some reason or other. The water accumulating in the intervening space found an outlet over the spur. This case presents features somewhat similar to that described by Philipp from the south side of the von Post Glacier (see p. 28).

Through Valleys.—Great through valleys running in a general N.W.-S.E. direction are a feature of some parts of Spitsbergen. The outstanding example is the Kings' Highway

Digitized by Google

connecting Kings Bay and the North Branch of Ice Fiord (see Isachsen, 1915, map, Feuille du Sud). This is occupied by ice over its whole extent. The Hörbye valley appears to be another example (Pl. II., Fig. 1; Tyrrell, 1922, Pl. I., Fig. 4). It runs north-west for about 10 miles to an ice col which may lead over to a glacier descending towards the head of Dickson Bay. A third example can be seen from the summit of Mt. Keilhau at the southern extremity of Spitsbergen, extending north-west towards the head of Horn Sound (Pl. I., Fig. 1). This probably joins up with the great Horn Glacier mentioned by Hoel (1918, p. 99). These long, straight depressions are believed to be consequent valleys, of pre-glacial age, dependent on the original slope of the Spitsbergen plateau from north-west to south-east, and analogous to the similar consequent valleys of the Scottish Highlands.

Acknowledgement.—The author is much indebted to the Carnegie Trustees for the Universities of Scotland for a grant in aid of publication of the illustrations of this paper.

EXPLANATION OF PLATES.

Plate I.

Fig. 1.—View looking north-west from the summit of Mt. Keilhau, near South Cape, showing a reticular glacier system. The distant mountains are part of the western coast range, the high sharp peak being the Hornsundstind. A well marked through valley (p. 46) runs towards the head of Horn Sound on the north side of the Hornsundstind group.

Fig. 2.—The Nordenskiöld Glacier, looking east from the summit of the Wordie Crags, north of Adolf Bay. This glacier is one of the major outflows of the New Friesland highland ice. The much crevassed terminal portion is due to ice-falls over the Pre-Devonian outcrop. Note iceberg just broken away into the waters of Adolf Bay.

Fig. 3.—Plateau type of glacier in Dickson Land (Scansen Quarter), viewed from the summit of Mt. Tyrrell, near C. Ekholm, Klaas Billen Bay. The latter appears in the foreground.

Digitized by Google

Plate II.

Fig. 1.—The Hörbye Glacier (right) viewed from the Wordie Crags, De Geer Mts.; Petunia Bay (head of Klaas Billen Bay) and the Ebba R. in the foreground. The Hörbye Glacier is probably an example of a dendritic glacier, and occupies a well marked N.W.-S.E. through valley. Note the circular kettle-hole lakes, one on each side of the Ebba R.

Fig. 2.—View, looking south, of the James Geikie and Sir Archibald Geikie piedmont glaciers, south of Ferrier Haven, Prince Charles Foreland. The rock ridge and patch of bare ground separating them can be seen in the middle distance (left). Raised beaches in the foreground.

Fig. 3.—View westward, from the sea, of the Monaco (Murray) and Buchanan piedmont glaciers, coast south of Richard Lagoon, Prince Charles Foreland. The two masses are separated by the rock ridge of the Nunatak, and the bare ground of the Trocadero Beach (middle distance). Background shows range of the Northern Grampians from Mt. Jessie (left) to Mt. Rudmose (right).

Plate III.

Fig. 1.—Corrie Glacier on south wall of the Carron Valley, Adolf Bay, Klaas Billen Bay. Carron Glacier in foreground. Note cascading ice from the plateau top over the edge of the cirque.

Fig. 2.—Macleod (left) and Wotherspoon (right) Corries, and horseshoe glaciers therein (see fig. 2, text), Campbell range, east side of Klaas Billen Bay. Penultimate stage of breaking up of the sea ice shown in foreground.

Plate IV.

Fig. 1.—Carron Glacier, Adolf Bay, showing right-angle bend, medial moraines, and nourishment from two cascade glaciers (see p. 24) descending from Mt. Robert. Note expansions of the ice on a ledge excavated in a weak stratum.

Fig. 2.—Ragnar Glacier, east of the head of Petunia Bay, Klaas Billen Bay. Shows good example of expanded foot glacier due to widening of the valley below the constriction caused by an outcrop of Pre-Devonian rocks. The glacier is an out-flow of the New Friesland highland ice.

Plate V.

Fig. 1.—View south from summit of Mt. Tyrrell, near Cape Ekholm, Klaas Billen Bay. Shows valley leading to Temple Bay (middle distance), with Colorado Hills beyond. On extreme right is the White Berg, capped by a typical ice carapace (see p. 16).

Fig. 2.—Tabular iceberg seen on Aug. 6th, 1919, off Duner Bay, Stor Fiord, and again seen a mile or two further south on Aug. 13th, 1920. Length estimated at half a mile. This was probably broken off the front of the Negri Glacier at the north end of Stor Fiord (see p. 12).

Fig. 3.—Ice-foot or shore ice on north side of Agardh Bay, Stor Fiord. On the left the ice is darkened with disintegrated shale (see p. 16).

Digitized by Google

Plate VI.

Fig. 1.—Ice-foot or shore ice adhering to boulder clay cliffs after break-up of sea ice, coast south of Cape Ekholm, Klaas Billen Bay (see p. 16).

Fig. 2.—Moraine-covered, sloping termination of the Pollock Glacier. De Geer range, north of Adolf Bay (see p. 32). The figure (Mr. C. M. Pollock) gives the scale.

Plate VII.

Fig. 1.—Termination of the Usher Glacier, Mohn Bay, Stor Fiord, looking north. Shows stage of stagnation or retreat, and broad hummocky terminal moraine. Hayes Glacier tongue in background, bounded (south) by the Krogh Berg, north by the Teist Berg (see p. 28).

Fig. 2.—Termination of the Duckwitz Glacier, west coast of Barents Island, now extending as a three-mile long tongue upon the shallow sea floor. Note crevassing and contortion of the marginal ice (see p. 29).

Fig. 3.—View eastward, along the southern margin of the Nordenskiöld Glacier, showing "shepherd's crook" moraines (see p. 33). Mts. Urmston and Cadell on right, Mt. Ferrier on left.

Plate VIII.

Fig. 1.—Surface of Nordenskiöld Glacier, showing stream channel excavated in ice; honeycombing due to dust wells in the foreground; ice-table (left); a medial moraine (left and middle distance); and the two great nunataks, Mts. Terrier and Ferrier, in the background (see p. 33).

Fig. 2.—Surface of Nordenskiöld Glacier, showing dirt-cone (foreground). The cone of ice within the veneer of dirt shown by the scrape in front. A medial moraine in middle distance, Mt. Ferrier in the background (see p. 33).

Plate IX.

Fig. 1.—View of the Wordie Crags, De Geer range, north of Adolf Bay, looking north-east. Shows horizontally-bedded limestone ridge, toothed and serrated by intense frost weathering. The height of the cliff at the far end is about 250 ft.

Fig. 2.—The pinnacle ("The Pin") at the west end of the Wordie Crags. This column is about 10 ft., high, and 1½ ft., wide. The broken rock lying about illustrates the severe frost shattering that is going on (see p. 39).

Plate X.

Fig. 1.—Fountain in moraine covering the termination of the Carron Glacier, Adolf Bay. The water spouts up about 2 ft., and disappears down a crevasse to reappear as a waterfall from a tunnel in the face of the glacier (see p. 34).

Fig. 2.—Facetted spurs in tributary of the Ekholm Valley, east side of Klaas Billen Bay (see p. 44; and fig. 5, text). Raised beach plattorm in foreground (see p. 42).

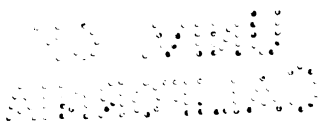
Digitized by Google

Fig. 1.

Fig. 2.

Fig. 3.

Digitized by Google



Digitized by Google

Fig. 1.

Fig. 2.

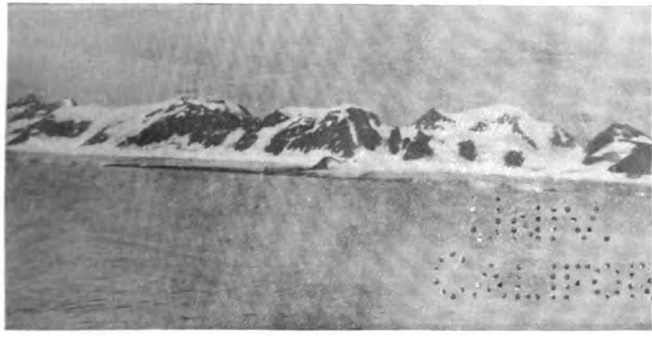


Fig. 3.

Digitized by Google

UNIV OF
CALIFORNIA

Digitized by Google

Fig. 1.

Fig. 2.

Digitized by Google

Digitized by Google

Fig. 1.

Fig. 2.

Digitized by Google

UNIV. OF
CALIFORNIA

Digitized by Google

Fig. 1.

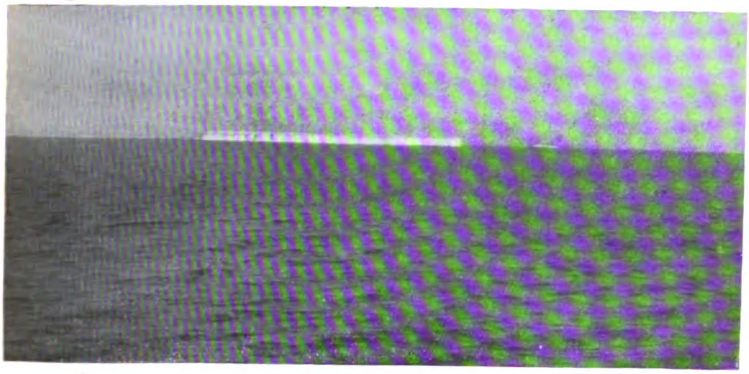


Fig. 2.

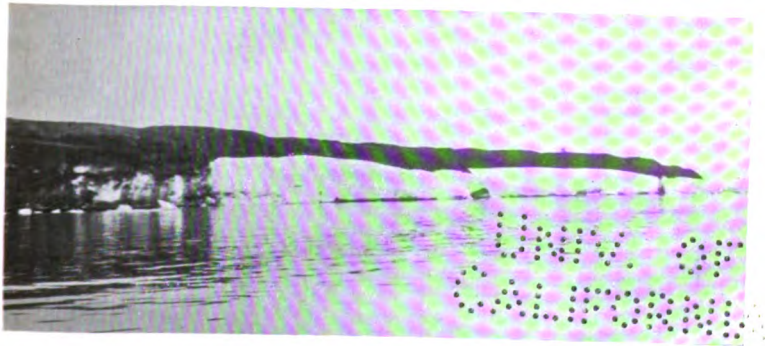


Fig. 3.

Digitized by Google

Digitized by Google

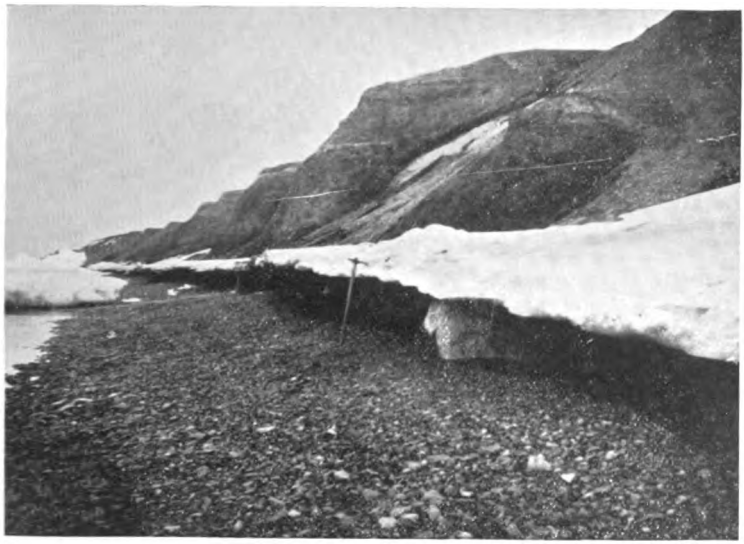


Fig. 1.

Fig. 2.

Digitized by Google

UNIV. OF
CALIFORNIA

Digitized by Google

Fig. 1.

Fig. 2.

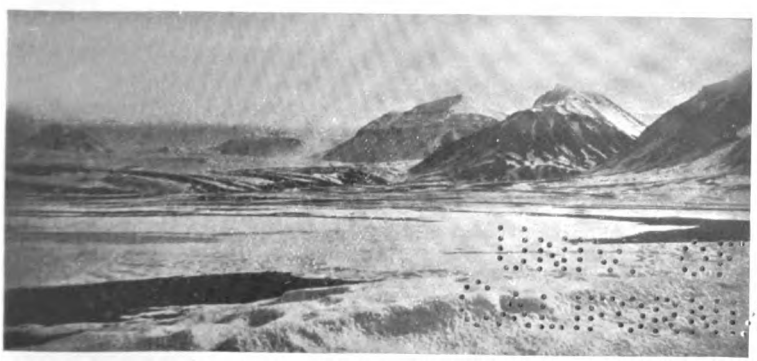


Fig. 3.

Digitized by Google

Digitized by Google

Fig. 1.

Fig. 2.

Digitized by Google

UNIV. OF
CALIFORNIA

Digitized by Google

Fig. 1.

Fig. 2.

Digitized by Google

Digitized by Google

Fig. 1.

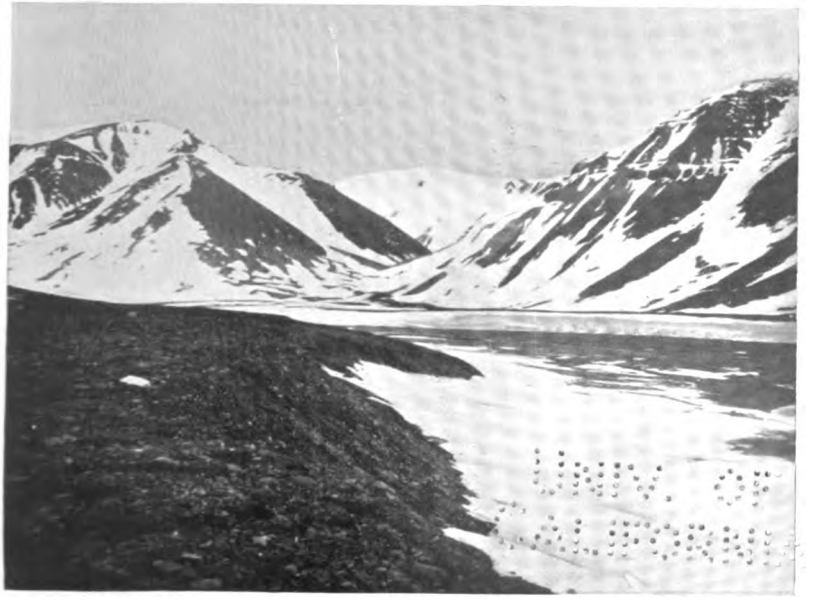


Fig. 2.

Digitized by Google

Digitized by Google

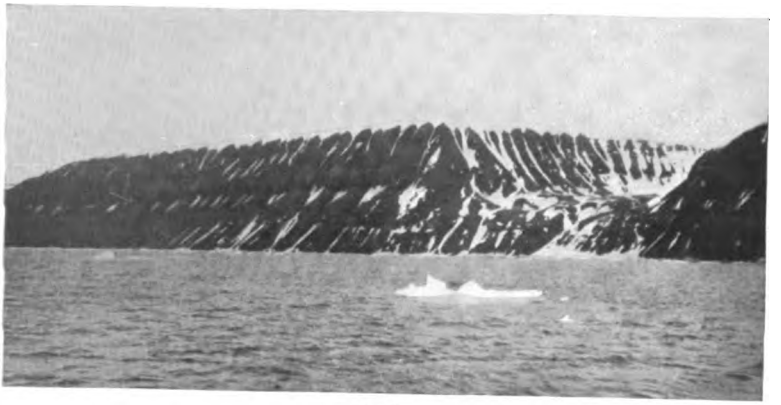


Fig. 1.

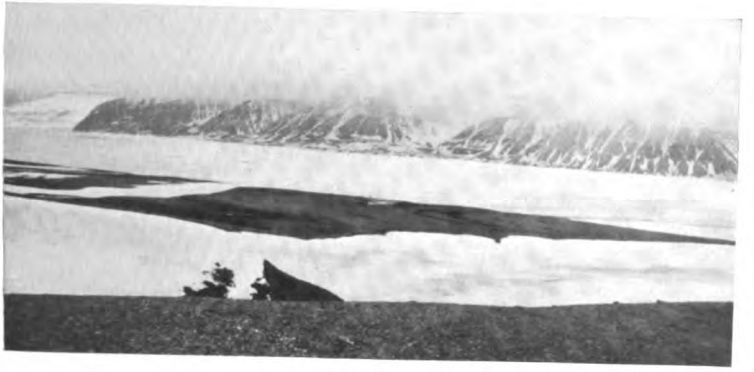
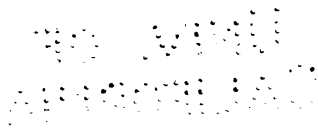


Fig. 2.

Fig. 3.

Digitized by Google



Digitized by Google

Digitized by Google

Digitized by Google

Plate XI.

Fig. 1.—Plateau edge of Nordenskiöld Land, south side of Ice Fiord, approaching Advent Bay from the west. Shows joint-control of gullies and snow-streaks, and ice forming a frilled surround to the plateau summit (see p. 46). Hanging valley due to cirque recession on the right (see p. 44).

Fig. 2.—View west across Klaas Billen Bay (ice-filled) from Ekholm Valley, showing curved concentric beach lines (mid-distance) connecting two main raised beach platforms (see p. 41).

Fig. 3.—Drift ice encountered on approaching entrance to Ice Fiord, June 10th, 1920. The land in the background is Prince Charles Foreland.

Plate XII.

Fig. 1.—Panorama of the outflow of the Ragnar Glacier from the New Friesland highland ice (see p. 13). Pre-Devonian mountains of the Newton-Chydenius range in the background. In foreground gypsum and limestones of the Upper Carboniferous. Mt. Sphinx on extreme left.

Fig. 2.—Front of the Nordenskiöld Glacier seen from the southern shore of Adolf Bay. Note upturning of the stratification planes of the ice near the margin, and the emergence of the ground moraine (see p. 36).

Plate XIII.

Fig. 1.—Panorama looking south and southwest from the rounded summit seen on the right of Whales Bay. Shows a typical reticular glacier system (see p. 18), of which the Strong Glacier (middle distance) is the principal trunk stream. Another trunk stream (Davis Glacier) seen in distance on extreme left.

Fig. 2.—Panorama of Whales Bay, mainland coast, Stor Fiord, seen from the north-east. Cretaceo-Jurassic mountains to the right; long black bar in middle distance is the lateral moraine of the Strong Glacier, built out into the sea during a recent advance (see p. 28).

Digitized by Google

No. II.—The Fracture of Homogeneous Media.

By James Weir French, D.Sc., F.Inst.P.

Geologists are concerned with the origin and growth of worlds, in the evolution of which all the complex forces of Nature are involved.

To elucidate the mystery of the earth's creation and to piece together the fragments of its past, the geologist applies the detailed knowledge of these forces as they are disclosed by workers in any of the varied spheres of science. By the application, for example, of the recently acquired knowledge of radio-activity, the earlier conceptions of the age of the earth have been profoundly modified.

Geology as a science has no boundaries, and the observations, therefore, of an optical engineer concerning the surface phenomena and fracture of homogeneous media may be of interest to the members of this Society.

Homogeneity is a relative term. According to Lord Kelvin—

> "The perfect fulfilment of this condition without any limit as to the smallness of the parts, though conceivable, is not generally regarded as probable for any of the real solids or fluids known to us, however seemingly homogeneous. . . . In other words, the prevailing belief is that every kind of matter with which we are acquainted has a more or less coarse-grained texture . . . and in the meantime," continues Lord Kelvin, "we need only say that the definition of homogeneous may be applied practically on a very large scale to masses of building or coarse-grained conglomerate rock, or on a more moderate scale to seemingly homogeneous metals, or on a scale of extreme undiscovered fineness to vitreous bodies, continuous crystals, solidified gums, as indiarubber, gum arabic, &c., and fluids."

There is a remarkable similarity in the prismatic cleavage of very homogeneous and isotropic optical glass and of comparatively coarse-grained sandstone, typical specimens of which are

Digitized by Google

submitted for your consideration. According to the statement of Lord Kelvin, just cited, the sandstone as well as the glass may be regarded, so far as fracture phenomena are concerned, as being truly homogeneous and isotropic.

In the first instance it is most convenient to study the surface phenomena and fracture of a transparent substance in which the strains introduced can be readily observed.

It is now generally recognised that the substance of a polished surface layer of such a material as glass differs in important physical respects from the original substance from which it is produced, and therefore from the underlying material. That vitreous substances differ structurally from crystals is well known. Crystals are built up by the grouping of their molecules according to definite systems. Their surfaces are natural, and, although they may be molecularly smooth, they are unpolished in the ordinary sense of the word. Whatever the material, polishing consists in disturbing the surface molecules to such an extent that their cohesion is sufficiently overcome to enable them to rearrange themselves just as the regular surface of a liquid is attributable to molecular mobility and the action of surface tension forces.

Whereas the molecular arrangement of the crystalline substance is an orderly one, there is no longer a definite arrangement of the surface molecules of the polished crystals. The arrangement of the polished surface molecules is probably a random one, and to the surface layer there has accordingly been applied the term "amorphous."

It may be anticipated that the physical qualities of the polished surface of a crystal will be different from those of a natural growth surface, and, indeed, it is well known that the weathering properties of a crystal are modified by polishing.

Since the substance of glass is itself amorphous, no crystalline structure being observable, to distinguish its polished surface layer as amorphous, as is so often done, is not satisfactory. The molecular arrangement of both the surface and the underlying material is presumably of the same type, a random one, but the surface layer molecules are probably differently compacted from those of the underlying material,

Digitized by Google

and there is good reason to think they are subjected to very considerable tension forces.

Crystals being the results of growth, it is possible to study their surfaces in both the natural and polished conditions. Glass, so far as we know, does not grow with molecular regularity, and to obtain a natural surface is impracticable. It is a substance that can only be obtained in a polished condition, and this polished condition can be attained in several ways. When a piece of glass is fractured, the forces at the advanced edge of the crack are very great. The molecules are profoundly disturbed and rearrange themselves, thus forming a surface akin to that of a mobile liquid. Fracture also produces a polished surface, and again, if a piece of glass is subjected to the required degree of heat, the thermally agitated surface molecules are enabled to rearrange themselves. This operation is termed "fire-glazing."

Chemical action produces the same effect. Prehistoric flint implements that have been buried for ages often present a highly polished patina or surface layer attributable to weathering or chemical action, which exhibits all the phenomena of a polished surface layer.

When glass is rubbed mechanically under suitable conditions, the agitated surface molecules rearrange themselves. Mechanical forces are indeed those that are commonly employed by the optician for the production of polished glass surfaces.

It was the late Lord Rayleigh who first drew attention to the pool-like character of a polished glass surface, to its molecular uniformity, and to the absence of any transition stages of development. Sir George Beilby first attributed the rearrangement of the agitated surface molecules to surface tension forces.

By rupturing metals with great suddenness, Sir George Beilby has obtained portions of the fractured surface that do not show surface tension flow. When a large block of glass is suddenly ruptured, surfaces that appear matte are obtained, but under the microscope these matte surfaces are clearly the result of irregular fracture; each small element of the surface appears highly polished. It is probably the case that no glass that has not an amorphous surface layer has ever been obtained.

Digitized by Google

In support of the surface layer theory, there is now a considerable amount of evidence. If the surface layer differs appreciably in its physical properties from the underlying layer, there should be little difficulty in practically demonstrating the fact. Crazing of glazed pottery is due to greater contraction of the thin surface layer of glaze than of the underlying clay, the result being that the surface layer becomes subdivided by cracks normal to the surface. If a piece of glass is polished mechanically and is heated to a temperature just below the softening point of the body of the glass, the amorphous surface layer, which is evidently under tension, cracks and becomes subdivided just as in the case of glazed pottery.

This appearance is illustrated in Fig. 1, Plate XIV., the right-hand specimen being an example of crazed pottery and the left hand a highly magnified specimen of polished glass heated as described. The surface in question was quite continuous before being heated.

If a parallel plate of glass is polished on both sides, and if the polished layer of one of the surfaces is then very carefully broken up by fine grinding, the other originally flat polished surface will become concave. Either the polished surface layer is subjected to tension or the rough grinding of the other side has subjected that surface to pressure. It is more probable that the bending is principally attributable to tension of the polished surface. If the second polished surface is ground, thus relieving the tension and possibly introducing some pressure, the plate again tends to become flat. But the experiment is not an easy one to conduct, as the amount of bending to be observed is small and the results may be vitiated by temperature effects, irregular grinding, and residual annealing stresses in the glass.

There are other interesting experiments that in the case of a polished substance suggest the existence of an amorphous surface layer under tension. If, for example, the surface is tapped gently with a hard, rounded point, there will be produced around the point a circular crack which penetrates the surface layer. The forces required to produce these surface cracks are extraordinarily small. They are very much smaller than those that would be obtained from calculations based on the physical constants of the material.

Digitized by Google

Some idea of the sequence of effects that contribute to the fracture of glass may be obtained from Fig. 2, which represents the various stages in the pressure of a steel ball upon a polished cube of glass placed between Nicol prisms in order that the strains introduced may be viewed. A very light pressure on the ball gives rise under crossed Nicols to a cone of white light (*b*) with a small amount of surface light at (*d*); the portions (*a*) and (*c*) appear dark. If the Nicols are paralleled it will be found that a very slight pressure has sufficed to produce a minute surface crack, the stresses at the edge of which are evidently considerable. If the pressure is increased and the Nicols are crossed, there may be seen a coloured sphere of light which is a clear indication of the production of the cone fracture indicated in the fourth view. A stage is next reached when the glass under the ball collapses. Under the impact the cone fracture may be extended in a

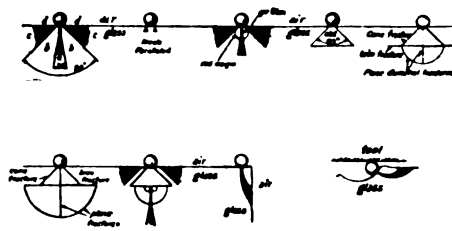


Fig. 2.

more or less horizontal direction, and there may be formed diametral plane fractures which are of considerable importance in the linear cleavage of glass by means of a hard point such as a diamond. By further pressure the diametral planes may be extended to the edge of the brim, as indicated in the sixth view. When the Nicols are crossed, the strain is as indicated in the seventh view. Frequently at this stage small coloured spheres are visible within the cone, indicating the presence of subsidiary cone fractures.

In these various examples, the ball having been applied to the centre of the block, the forces on either side are balanced. If the ball is applied to the edge, the central cone A of the first view will be deviated towards the side and ultimately a

Digitized by Google

conchoidal splinter will be formed. From these experiments an idea of what occurs in the abrasion of glass is obtainable. For example, in the ninth view there is indicated the action of a round particle wedged into a depression of the glass surface. The horizontal movement of the tool which grips the particle throws sufficient force upon the glass to produce a conchoidal splinter, and the nature of the process is such that conchoidal splinters are formed instead of cone fractures, the presence of which would be disastrous from the point of view of the optician.

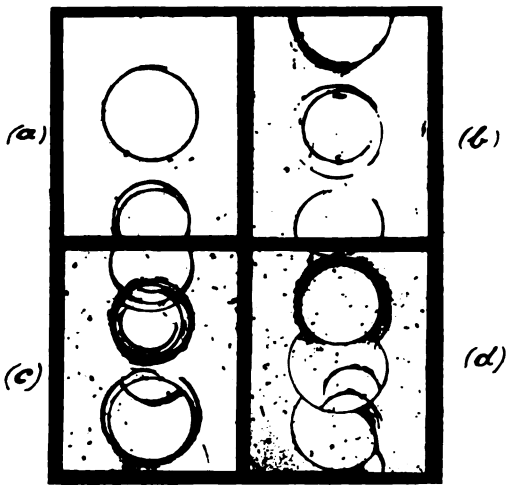


Fig. 3.

Owing to the fineness of the surface cracks, it is not easy to observe them until they have been emphasised by etching. Several types of percussion cracks in a homogeneous material, in this case glass, that have been made evident by etching are indicated in Fig. 3. A truly circular crack will be seen at (*a*); (*b*) shows a spiral crack, doubtless attributable to a slight spiral movement of the ball on the surface of the glass during the application of the pressure; (*c*) shows a number of concentric cracks, and also, in the case of the lower circle, an inner portion terminated by an earlier outer crack. At the top of this figure (*c*) it will be observed that, corresponding with an inner terminated crack, there is another that has been continued beyond, presumably, the original crack. In Fig. 3 (*d*)

Digitized by Google

the central circle is very clearly terminated at the outside of the top circle.

What is technically known as a sleek consists in the ideal condition of a ploughed groove, the sides of which are clean and free from any evidences of percussion cracks or conchoidal fracture. The perfection of the particular sleek illustrated in Fig. 4 will be realised when it is compared with the typical scratch indicated in Fig. 5.

Fig. 4.

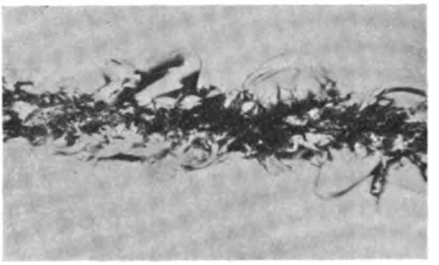


Fig. 5.

If a hard point in its passage over the surface of the glass chatters, and provided the impact forces are not too great, there will be produced instead of the sleek a series of surface

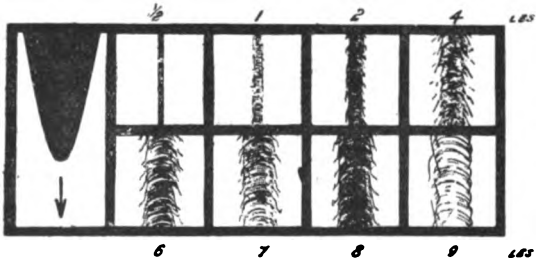


Fig. 6.

percussion cracks, several examples of which are indicated in Fig. 6. Loads varying from half a pound up to 9 lbs. were

Digitized by Google

applied to a gramophone needle of medium hardness, the needle being drawn over the glass in the direction of the arrow. It will be seen that the cracks present their convex sides to the direction of motion. The needle has evidently jumped forward and in striking the material has compressed it in front and pulled it at the rear. It has accordingly parted behind the needle and not in front. At pressures of from 2 to 8 lbs. there will be observed tangential cracks, as if the material had been forcibly torn from the sides, just as a piece of tissue paper or the finished surface of leather can be torn when a point is drawn over it.

Fig. 7 shows the effect of drawing a knife blade over the surface of glass. In this view numerous small lines that have been emphasised by etching are visible. Most lines of

Fig. 7.

this kind are really very fine series of percussion cracks, so fine, in the majority of cases, that careful examination under the microscope is required to distinguish their discontinuous character.

The probable existence of amorphous surface layers of the same general type in the case of glass or other homogeneous material that has been fractured, fire-glazed, or mechanically polished, has already been referred to. Surface percussion cracks on a fire-glazed surface are indicated in Fig. 8 at (*a*), and on a fractured surface at (*b*), the loads on the needle point being in each example 2 lbs. and 8 lbs. respectively. In the case of the heavier load at (*a*) the gramophone needle point has become flattened. In the case of the fractured surface under a load of 4 lbs. the needle has been allowed in the first instance to penetrate the surface, a cone fracture with diametral planes has been formed, and in producing the series of percussion cracks the longitudinal plane has been continued. It is evident in the photograph as a central black line of cleavage.

It is well known that marks made on glass by means of a French chalk pencil cannot easily be cleaned off. French chalk

Digitized by Google

is an insoluble material that adheres tenaciously to glass, but these characteristics do not provide a satisfactory explanation

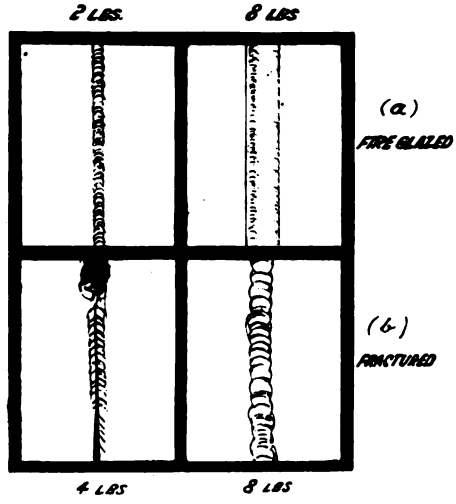


Fig. 8.

of the phenomenon. If a small quantity of French chalk is dusted on the surface of a piece of polished glass and over this

Fig. 9.

there is drawn a metal or even a pencil point, then, after very careful removal of the French chalk so far as possible, the surface when etched will appear fractured as indicated in Fig. 9.

Digitized by Google

If the glass in the unetched condition is breathed upon, condensation presumably takes place along the cracks, thus bringing the markings into view, and it is also possible that minute fragments of the French chalk may become wedged into the cracks. To remove them is hardly possible. If the glass is polished they gradually extend into the underlying material, and, although they may not be visible, they can always be exposed by etching. Glass tubing through which a piece of metal has been passed is very liable to crack. The explanation doubtless is that the interior fire-glazed surface layer is under great tension owing to previous solidification of the outer

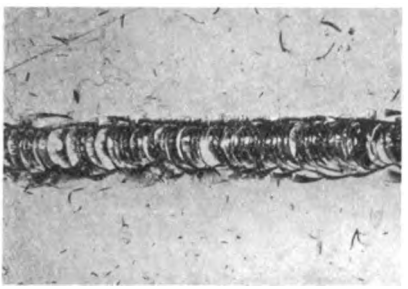


Fig. 10.

surface and that the passage of the metal produces surface cracks of the type illustrated, which may readily extend themselves.

To avoid the use of hard materials when cleaning particularly the inner surfaces of glass vessels is very important.

Several chemically clean vessels were obtained direct from the suppliers and their interior surfaces were examined for percussion cracks, which were found in great profusion. It is quite conceivable that these percussion cracks may occlude gases or even liquids in sufficient quantity to vitiate precise physical experiments, and it is quite possible that the difficulty of removing the last traces of gases supposed to be included in glass may be attributable to a similar cause.

Light blows upon a homogeneous substance such as glass produce circular cracks and cone fractures. Similar blows or pressures upon natural crystal surfaces may give rise to the well-known percussion and pressure figures of stellate form. If,

Digitized by Google

however, the crystal surface is mechanically polished, approximately circular percussion figures are obtained, as indicated in Fig. 10 of a polished quartz surface; but it will be observed that the circular cracks appear to spread irregularly beneath the surface layer, tending presumably towards the stellate form in the underlying crystalline medium.

From the geological point of view, ring fractures which have been described by Mr. E. B. Bailey,[1] with particular reference to Iceland, are of considerable importance.

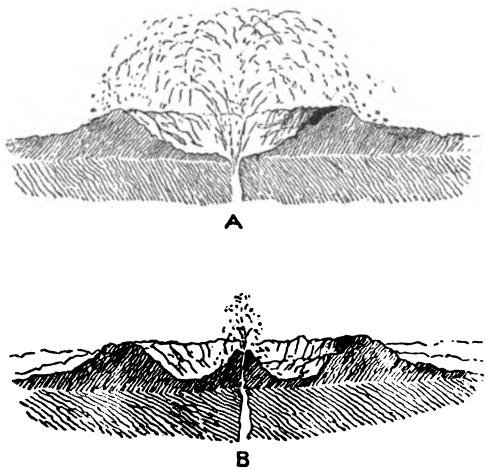


Fig. 11.

That the remarkable circular craters of the moon may also have originated in percussion fractures has been suggested, as for example by Suess. According to James Nasmyth, the circular lunar ridges have resulted from the ejectment of material from a central vent, as at (*a*) in Fig. 11, reproduced from the original paper.[2] At some later date the activity he assumes to have been much reduced, a central cone being thus formed, as at (*b*), and in some cases a level floor was produced by a flow of lava.

That so definite and sudden a change of activity should have occurred in the formation of so many of the lunar craters can

[1] *Geological Mag.*, vol. vi, Oct., 1919.
[2] *Quarterly Journal of Science*, vol. i, 1864, p. 388.

Digitized by Google

hardly be credited. There is more reason to suggest that they are the result of percussion fractures, caused by the impact of large meteorites that have fallen into the moon. Although the meteorite might break into fragments which would spread themselves over the surface, there would be produced a cone

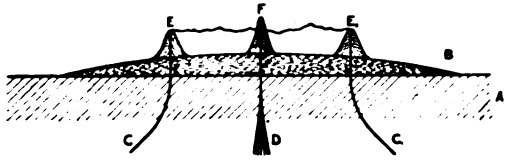


Fig. 12.

fracture and possibly central intersecting planes similar to those producible in glass and over these regions of weakness volcanic activity would be most likely to occur. Thus the peripheral ridge and the central cone might be formed simultaneously instead of at two stages, as indicated in Fig. 12.

There are three craters visible on the lunar map, the arrangement of which has some resemblance to the series of percussion cracks on glass represented in Fig. 13. With regard to these

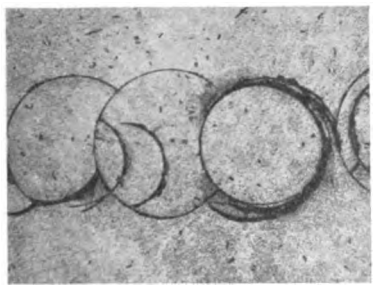


Fig. 13.

lunar craters, Theophilus, Cyrillus, and Catharina, it is generally considered that Theophilus, the lowest crater, is of most recent date, since in its formation it has invaded and partially destroyed the ring of the presumably older adjacent crater, Cyrillus. But if these lunar craters are the result of percussion cracks, a reversal of the ages of Theophilus and Cyrillus is involved; Theophilus, so far as the cone fracture is con-

Digitized by Google

cerned, would be first formed, the cone fracture of Cyrillus being evidently of later date, as it is terminated by the former.

Having indicated the ease with which the surfaces of homogeneous media can be ruptured, it will be of interest to consider the extension of surface cracks through the action of tension forces attributable in the majority of cases to differential contraction of the material. Reduction of volume may be due to thermal contraction, as in the case of basalt, or to evaporation of moisture, as in the case of starch, or possibly to chemical changes and crystallisation, but an increase of volume is frequently associated with this last mentioned cause, as, for example, in the case of plaster of Paris that has set, but which continues to expand thereafter for many months.

As reduction of volume is associated with thermal contraction and also with evaporation, it is convenient to consider columnar structure of basalt in comparison with that of starch.

When a block of starch is dried, the outer surface sets while the inner portion continues to contract. Under the tension forces thus created in the interior rupture either partial or complete of the substance will occur at a depth determined by the particular degree of stiffness at which fracture can occur. Thus there is formed a distinct layer which may be entirely separated from the underlying material or separated from it only by a plane or region of weakness.

As the layer continues to harden and contract, prismatic subdivision that has originated at the first hardened surface, that is, the outer, extends normally inwards unless the deviation is modified by some change in what is equivalent in cooling basalt to the isothermal plane. Meanwhile the inner portion has continued to contract with the formation of a series of layers each of which subdivides prismatically, as is indicated in Fig. 14, which shows a block of starch, a portion of the two outer layers of which has been removed, thus exposing an inner core that will later follow the same course.

If the layer is terminated by a surface of weakness not an actual fracture, the prism ends will be irregular or even granular. The columns may extend regularly to the face before its actual formation. When the columns separate they will then frequently be terminated by cup joints, a number of which are

Digitized by Google

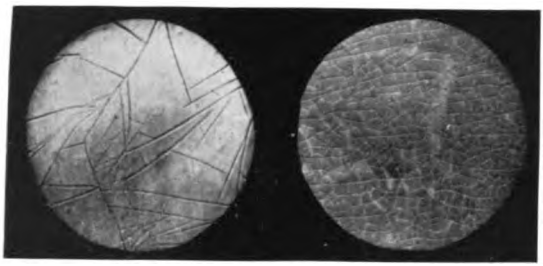


Fig. 1.

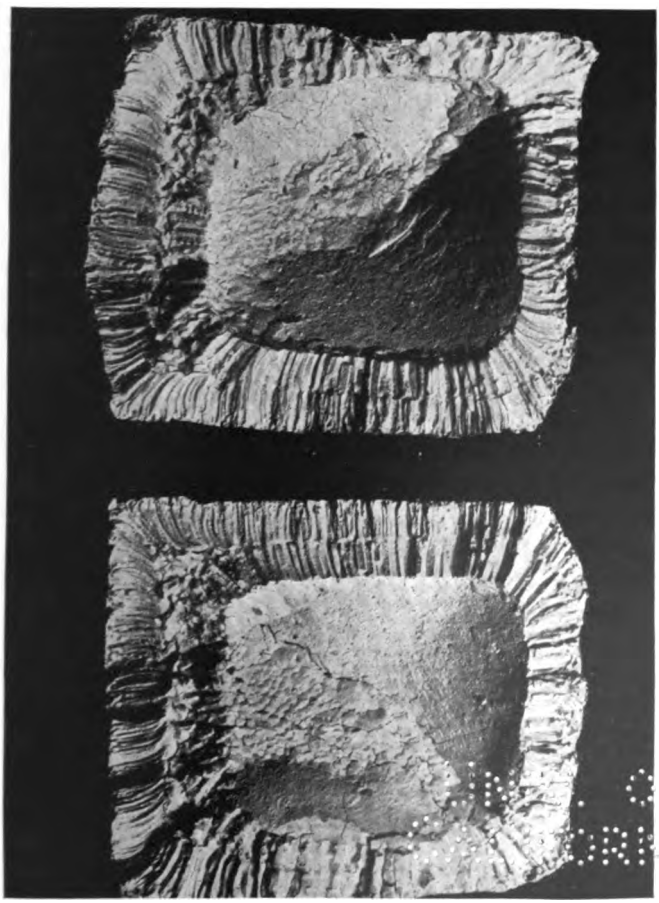
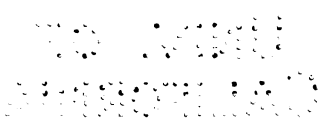


Fig. 14.

Digitized by Google



Digitized by Google

visible in the illustration, and the formation of which in basalt has been the subject of so much geological controversy.

If when the under surface of the layer has definitely formed it remains in contact with the underlying material, then the prisms may extend through the surface into the next layer, as is so frequently the case in basalt, but if the surface has definitely separated there may not be continuity across the face. This feature is particularly common in starch formations.

Cup joints, according to Mallet, will generally present their concavities towards the outer face from which cooling or hardening has proceeded, but further transverse subdivision of the basalt prisms between the original joints may result in cup joints, the orientation of which will depend upon the distribution of the longitudinal contraction and must be fortuitous.

Many theories of columnar structure and jointing have been advanced in the past. At one time the spheroid theory of Mr. Gregory Watt received the recognition of geologists of repute. This theory was based upon the frequent occurrence of concentric layers in exposed basalt prisms.

It is of interest to compare this appearance of onion-like layers with the starch specimen (Fig. 14). Pebbles that exhibit similar layers have been illustrated and described by Prof. James Thomson in a lecture which he delivered to this Society in 1877, his lecture being an elaboration of one first published by him in 1862. Prof. Thomson rejects the spheroid theory, which appears to be untenable, and accepts the purely mechanical explanation of fracture resulting from thermal contraction attributable to the cooling of the basalt from one or more surfaces.

In a lecture on the same subject delivered by Robert Mallet to the Royal Society in 1874, the mechanical explanation is elaborated in greater detail, but Mallet does not agree with the explanation of cup or ball and socket joints proposed by Prof. Thomson. The latter regards the basalt column as being unconstrained externally. When the surface has set, further contraction will establish tension in the interior and compression of the outer layer, and this condition is inconsistent with the origin of fracture at the surface. He believed, therefore, that cup fractures start at the centres of the columns and spread outwards.

Digitized by Google

Mallet, on the other hand, considered the whole column to be subjected to a longitudinal tension force, which would be the case if the contracting columns were constrained say at its ends, and also to a radial tension due to radial contraction. Fracture would then occur normally to the resultant force, the fracture therefore being cup-shaped and originating at the surface.

It is probable that both sets of conditions occur in Nature, as specimens of fracture that corroborate both views are common.

The layers observed in weathered pebbles, several specimens of which are illustrated in Prof. Thomson's paper, are comparable, I believe, with the jointed layers of basalt and starch; but whereas the latter are apparently due to the contraction of the material underlying a fixed outer surface, the layers of the weathered pebbles may be due to the general expansion by weathering of the outer layer, and therefore its withdrawal from the fixed underlying material less affected by weathering. The conditions are as it were reversed in the case of the weathered material.

Prismatic columns extend normally from a surface of cooling, and their straightness thereafter is determined by the shape of the interior isothermal surfaces. Thus in the case of a sphere of glass the columns will radiate from a centre, there being good reason to believe that they originate at the centre and spread towards the outer surface which they may not actually reach. This is consistent with the theory of Prof. James Thomson, and is understandable when the compression to which the outer layers are subjected is considered.

These conditions are not so marked in the case of starch, and it will be observed in Fig. 15 that the prisms are comparatively well defined near the outer surface at which subdivision has commenced, at first in an irregular manner which has quickly become more regular. The radial arrangement of the prisms normal to the Isohygral surfaces, that is, surfaces of equal wetness, is well indicated.

Similar radial structure in glass is illustrated in Fig. 16, which represents portions of two large glass drops that have been quickly quenched.

Digitized by Google

In neither specimen have the prisms definitely reached the outer layers which must have been under great compression as a result of the tension forces in the interior. At the centre the material is definitely subdivided. Several somewhat indefinite layers are observable in the case of the right-hand specimen.

These two specimens are really portions of very large Rupert's drops, which ordinarily are small beads of glass drawn out tailwise when hot and quenched in water. They are supposed to have been first made in Holland, and were introduced into this country by Prince Rupert, after whom they are named. A glass specimen that shows cup fracture is illustrated in Fig. 17. The rod of glass was gathered layer by layer on the end of an iron tube and was air-cooled, but the cup fracture traverses the successive layers obliquely, particularly at the outer edge. It does not run parallel to the gathering layers.

Radial prismatic structure in glass that has occurred on a much larger scale is represented by the specimen in Fig. 18, which was obtained from a melting of optical crown glass that was cooled at a rate sufficient for the formation of prisms, but not so quickly as to shatter the glass into thin dish-shaped splinters.

As the glass was of the best optical quality that had been stirred for many hours in the process of manufacture, the material may be regarded as being very homogeneous, although not isotropic in view of the stresses due to defective annealing, which must have been considerable but not so great as to give any appearance of colour when tested by polarised light. The dimensions of the pot were 24 inches diameter and 24 inches height, the material being Stourbridge clay mixed with 30 per cent. of burnt clay.

After the final stirring, during which the temperature fell below 1000° C., the pot of glass was withdrawn from the furnace and quenched externally over all with cold water. For about eighty hours thereafter the pot was allowed to cool at a slow and regular rate.

Fracture of the glass contents occurred radially from near the centre to the sides and base of the pot. The specimen illustrated being a portion taken from the right-hand side at a

Digitized by Google

position about one quarter from the bottom, its position in the pot was that indicated on the slide, the columns being directed towards a central region just below the surface.

It might be readily assumed that, since the glass was cooled externally where the chilling must have been severe, the fracture would commence at the outer surface and spread radially inwards. These are the conditions that appear to apply in the subdivision of a basalt dyke, chilled, for example, by contact with the adjacent rocks, or in a slab of starch that has dried. There can be little reason to doubt that the subdivision of a homogeneous material into prisms depends upon the particular conditions under which the subdivision takes place, and may, therefore, be very varied.

From the illustration it will be evident that the prisms have not extended to the side of the glass. That they should do so is not to be expected when it is considered that, owing to the very poor heat conductivity of glass, the outer layers must have been placed under compression by the tension of the inner contracting portions.

It was observed that at their inner ends, that is, near the centre of the pot, the prisms were abruptly terminated at a comparatively smooth nodular surface from which they radiated. To break this nodule was difficult; it behaved like toughened glass. There can be little doubt that its surface layers were held in compression by the tension of its interior parts, and, therefore, any surface cracks that might have been formed would be held closed and their extension would be prevented. As the prismatic structure ended abruptly at the surface, there being no sign of its continuation within the nodule, it is evident that the surface of the nodule was not of later date than the surfaces of the prisms. Its formation was the first incident in the series of events. At the moment of separation of the nodule, its material would tend to move towards its centre; its surface would move to a place of smaller area, and, being thereby compressed, the formation of normal fractures would be prevented. But the material external to the nodule would withdraw towards the outside; its surface adjacent to the nodule would move to a position of greater area and would necessarily crack polygonally. These cracks would instantly

Digitized by Google

Fig. 15.

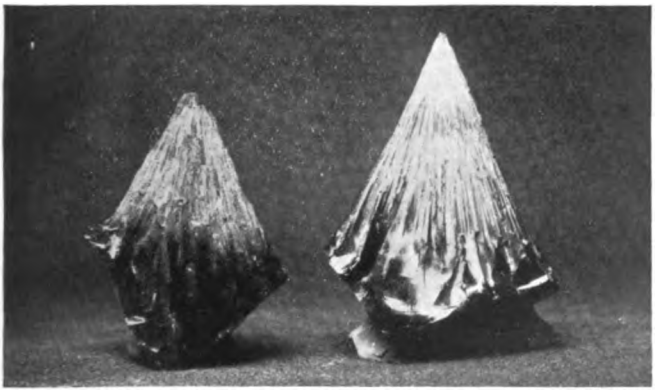


Fig. 16.

Fig. 17.

Digitized by Google

Digitized by Google

spread outwards. That the action started from the centre and not the outside is indicated, as was previously stated, by the close adhesion of the prisms at their base, as compared with their inner ends.

Several of the prisms recovered from this particular melting of glass are illustrated in Fig. 19.

Recently, through the courtesy of Mr. Currie, of the Scottish Central Glass Works, Alloa, I had an opportunity of examining the columnar structure that had developed in the lowest sandstone course of the side walls of a small tank glass furnace.

The walls comprised two upper courses of fireclay blocks in which no columnar structure developed, and a bottom course of rough-grained sandstone blocks obtained from the Penshaw Quarries, Durham. Their cross-section was about 1 square foot. Firebrick jack-arching formed the floor of the tank, under which was situated the regenerator, but between the floor and the regenerator there was an intermediate air space.

The sandstone course was laid in August, 1913, and, after almost continuous use of the furnace it was taken down in November, 1921. It was during this operation that the columnar structure that had developed was observed. When the tank was being emptied preparatory to its reconstruction, the floor at one portion failed, and glass discharged itself through the intermediate space above the regenerator roof. Thus, while the walls were being rapidly chilled, the floor was maintained at a comparatively high temperature, but there was no clear evidence that would enable a definite decision to be arrived at as to whether the columnar structure was formed slowly during the working of the furnace or more rapidly during the final operation of emptying the tank. That it was formed during the last mentioned stage, and was, therefore, of recent origin seems, however, to be probable for the following reason:—

At the joint between the sandstone blocks and the superimposed fireclay course a considerable amount of corrosion had occurred, a deep V-shaped groove having been formed.

In Fig. 20 the dark oblique right-hand face of the specimen is a portion of this V-shaped, corroded face, the lower portion of the specimen being the bedded surface of the block. It will be

Digitized by Google

seen that the prisms are disposed approximately normally to the bottom surface, and that at their upper ends they curve towards the oblique, corroded face. This would seem to indicate that a more or less oblique face existed before the prisms were completely formed.

Another specimen which shows straight columns is indicated in Fig. 21, the black lower portion being again a part of the corroded " V " joint.

Some of the prisms were of much larger section and better defined than others. A specimen of this kind is illustrated in Fig. 22, which is a side view, and Fig. 23, which is an end view of the same piece. The true columnar section of the structure is well represented in this latter view.

Several isolated columns are represented in Fig. 24. Their surfaces, it will be observed, are well defined, notwithstanding the comparatively coarse grained and open texture of the Penshaw sandstone, of which they are formed.

In conclusion, it may be of interest to consider the specimen represented in Fig. 25, which shows columnar structure that has been experimentally developed in a layer of baked fireclay of about 1½ inch thickness. The layer in question was the base of a small experimental optical glass pot of 12-inch diameter and 12-inch height, the pot being made of Stourbridge fireclay. The pot, with its contents of optical glass at a temperature of from 1200° C. to 1300° C., was wholly immersed in a tank of cold water for several minutes. Columnar structure that traversed the whole thickness of the fireclay was developed, as indicated. In the glass itself there was no evidence of any columnar structure. If such a structure had occurred also in the glass, it is probable that it could not have proceeded far, as the contents other than the outermost layer must still have been viscous in view of the small heat conductivity of the material. The thin layer of glass adjacent to the fireclay was greatly shattered, as is to be expected, and the presence there of columnar structure could not, therefore, in any case have been detected.

Digitized by Google

Fig. 18.

Fig. 19.

Fig. 20.

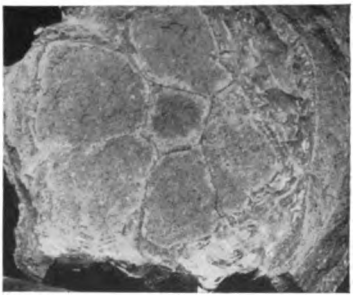


Fig. 25.

Fig. 21.

Fig. 22.

Fig. 23.

Fig. 24.

Digitized by Google

Digitized by Google

No. III.—Some Fissures in the Strata of Benmore Hill, Cowal.

By John MacGregor.

The following quotation is taken from the New Statistical Account of Scotland, published in 1845:—

"On the sides of Benmore there are several very remarkable fissures or chasms running parallel with the acclivities of its sides varying in width from 10 inches to 15 feet. The one found to be deepest is about 3 feet wide. A stone dropped into it (striking, of course, against the sides in its descent) takes 58 seconds to reach the bottom. Its last fall is distinctly heard to be long, and sounds as if terminating in a body of water."

Even after making a generous allowance for obstructions to the speed of a falling body, this period of 58 seconds would imply that the depth of the fissure is to be measured in miles! No further published reference to these chasms could be found, but they seemed to deserve more attention than they appear to have got. By the kindness of the gamekeeper, Mr. Grindle, and his assistant, Mr. Crosbie, we were guided to this interesting spot.

The area in which the fissures occur lies in the angle between Glen Massan and Glen Eachaig, about 3 miles N.W. of the head of the Holy Loch. A line drawn from Ben More House to the peak A Chruach (1570), passes very nearly through the area containing the cracks; this area is almost exactly on the 1000-foot contour line. The rocks belong to the mica-schists, albite-schists, &c. (*g*) of the Cowal map and memoir. The average slope of the hillside from the 100-foot up to the 1000-foot contour line is about 21°, but a good deal of the slope nearer the top is at an angle of about 32°. On the map (Fig. 1) NS is a north-south line, and PT, PU, PV are wire fences. The area containing the most dangerous fissures was formerly enclosed by a fence and wire netting, but most of these are now decayed. Some of the narrower parts of the cracks are quite hidden by heather, and part of the area is

Digitized by Google

covered with closely planted scrubby pines. Accurate mapping is, therefore, difficult. Small parts of cracks are seen at C, D, E, K, and M. The cracks at F, H. L, and Q are quite clear. The continuous lines at F, H, L, and Q indicate deep chasms; the dotted parts of the lines F, H, and L show that there is a depression in the ground there, but no deep hole is visible. There is little doubt, however, that the cracks at

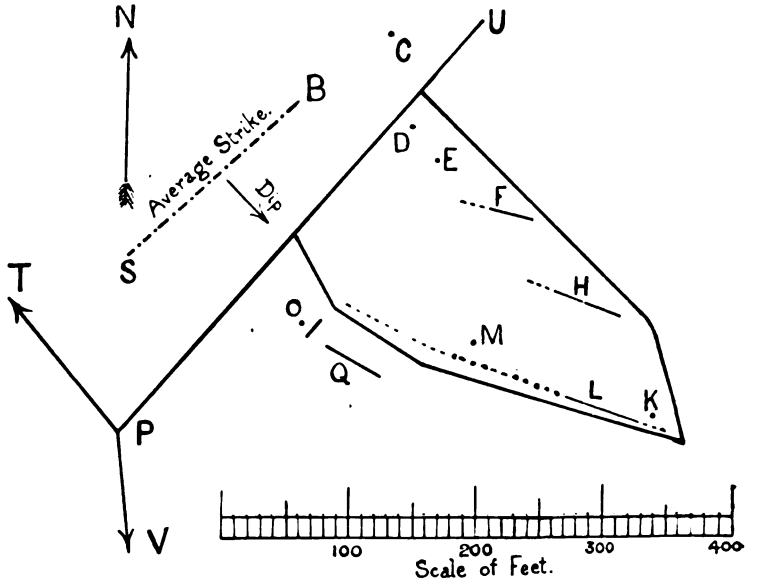


Fig. 1.

the places where the dotted lines are, are bridged over in some way, probably by boulders which are now covered with a layer of turf.

The crack at Q is overgrown with heather. It is about 10 inches broad, about 30 feet long, and 35 feet deep. The bottom is dry.

At O there is a pit about 3 feet in diameter and about 12 feet deep.

At L the crack is about 68 feet long and about 40 feet deep. It looks about 9 or 10 feet broad. The bottom of it is visible, but there is no doubt that what is seen consists of matter

Digitized by Google

which has fallen in, and that the crack goes to a far greater depth.

The crack at F is about 2½ feet wide and 80 feet deep. The bottom is dry.

The crack at H is about 27 inches wide at its widest part and 130 feet deep. It narrows gradually towards the eastern end, where its breadth is only about 3 inches. Removal of the heather would be necessary if one wished to trace it farther. This crack contains water that was estimated to be reached at a depth of about 100 feet. The lower 30 feet of the plumb line came up stained with very dirty water; a stone dropped into the chasm could be heard producing a distinct splash. Along the side of the hill there must be some exit for the water from these cracks. An examination was made along the side of the hill to the east, but although one or two deep crevices were seen, it was doubtful if they had any connection with F, H, L, or Q. A dense pine plantation along the face of the hill makes observation very difficult.

At C there are traces of a crack and of a pit, this latter having been at some time covered with an iron grating; one iron bar is visible.

It is interesting to note that the direction of the cracks is very nearly parallel with Glen Massan. SB, the average strike of the strata in Cowal, is taken from the 1-inch scale, Geological Map of Scotland, sheet 29.

The cracks are not quite vertical, but hade towards the S.S.W., making an angle with the horizontal which exceeds 80°. The hade is not uniform. A stone, dropped down the crack H, strikes the side at a depth of about 20 feet and disappears round a curve, after which a short time elapses before it is heard to strike against the rock again. This fall and collision are repeated at least once more, thereby indicating that a vertical section of the crack is somewhat like Fig. 2.

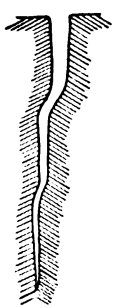


Fig. 2.

The period of "fifty-eight" seconds mentioned in the Statistical account is very likely a misprint for "five to eight" seconds.

Digitized by Google

If these cracks are pre-glacial, it is difficult to understand why they are not filled with drift. No rounding of any edge of a crack was noticed. Further, they cannot be of great age, or they should have been full of organic remains. The rapid diminution in the breadth of crack H is remarkable; this chasm is very like what would be produced if a sharp-edged pocket knife were stuck deep into a mass of putty.

How are these curious fissures to be explained?

A brief study of a geological map of Cowal reveals a close connection between the directions of the valleys and the geological structure. There are two main directions, in one or other of which almost all the valleys run. There are the N.W.-S.E. valleys such as Glen Finart; there are the N.E.-S.W., such as Inverchaolain Glen. The former of these directions is approximately parallel to the numerous basalt dykes; the latter direction coincides nearly with the strike of the strata. One does not require to assume that a dyke lies along any of the N.W.-S.E. glens; it is sufficient to know that the very great number of basalt dykes in that direction presupposes a tension of the rocks; and denuding agents would form valleys along lines at right angles to that tension. A stretched piece of rubber is more easily cut across than along the line of tension. Evidence of this tension in the rocks of Cowal is very common; one of the best places in which to observe this is on the Bullwood shore about two miles south of Dunoon. One very clear exposure has the appearance shown in Fig. 3.

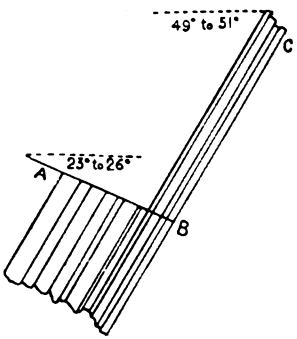


Fig. 3.

Digitized by Google

CB shows the dip of the strata. Rock has been removed from the space between CB and AB. The face of AB is covered with a layer of white quartz. One might have expected AB to be perpendicular to BC, but it is not. It would be interesting to learn the average value of the angle ABC in other parts of Cowal. The strike in the Bullwood strata is about 25° to 30° to the south of west.

Another interesting feature which is represented in the following diagram, Fig. 4, may be seen in the Bullwood strata.

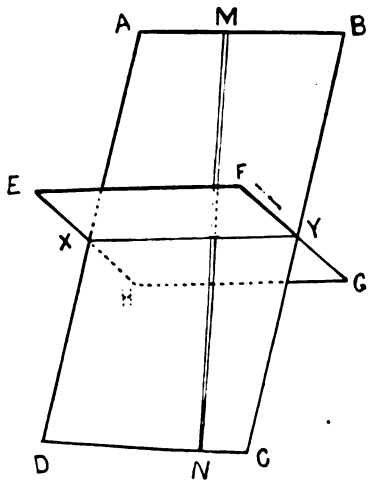


Fig. 4.

Let the plane ABCD represent the dip of the strata and let the plane EFGH be the layer of quartz which has filled up a crack across the strata. It will be found that the line XY, the intersection of these planes is not horizontal but dips at an angle of about 5° towards X, that is in a direction along the strike. In the plane ABCD cracks like MN are seen, which are nearly perpendicular to XY; they dip about 85° to the S.E.

Two distinct eras of upheaval are therefore seen—

(1) That which has lifted the stratum ABCD near the Bullwood quarry so that it now makes an angle of about 50° with the horizontal. During this upheaval the crack EFGH was produced, and this crack is now filled with quartz.

Digitized by Google

(2) A more recent upheaval which in the Bullwood is not more than about 5°, and is roughly at right angles to the first. It has produced the nearly vertical crack MN. Is it possible that the numerous N.W. basalt dykes in Cowal have any connection with this later upheaval, and is it connected with these comparatively recent Benmore cracks?

One very striking result of these two distinct tensions combined with the dip of the strata is seen when rock is blasted in the Bullwood quarry. The blocks of stone have a tendency to split into large rhombohedra, the faces of which are bounded—

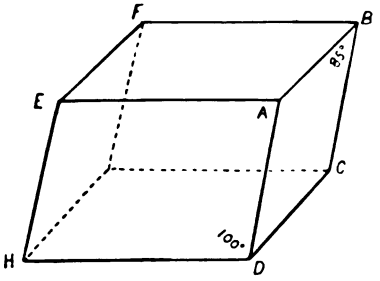


Fig. 5.

(1) By the plane of dip ABCD or EFGH.
(2) By the faces ABFE or DCGH, which are sometimes covered with quartz, and which are inclined to the first planes at an angle ADH, roughly about 100° to 110°.
(3) By the planes ADHE and BCGF, which are inclined to the planes ABCD and EFGH so that the angle ABC is about 85°.

The angles between these three sets of planes are not constant, but the production of rhombohedra is very distinct. If rhombohedra of this sort occur in other parts of Cowal, measurement of their angles would be interesting.

A crack on the side of the hill near Corantee, which is on the west side of Loch Eck, a part of which crack forms the well known "Paper Cave," should have its length, breadth, depth, and direction determined.

Digitized by Google

No. IV.—Notes on the Chitons of Woodmill.

By Robert Dunlop.

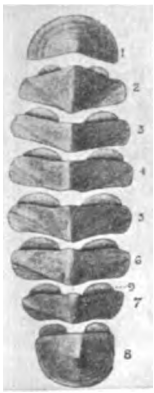


Fig. 1.—1. Cordatus.
8. Armstrongianus.
2-7. Gemmatus.
9. Apophyses.

Since my last note to this Society, in 1913-14, on the Woodmill Chitons, I have made some further observations that are worth recording. The fact that all the Chitons in Scotland have eight plates, six of them slightly different, and two distinctly so, has given me cause to consider whether the plates found at Woodmill do not all belong to one species.

In the first place, they all seem to have been living in a little carboniferous pool about 10 or 12 feet broad, but of unknown length, as I have worked in only about 2 feet.

Out of this pool I have recovered over eighty specimens of *Gemmatus*, fourteen of *Armstrongianus*, and twelve of *Cordatus*. These have been sometimes found together, and their relative numbers suggest that they represent but one species of Chiton. All three also present the same microscopic structure.

When a modern Chiton is carefully examined, it is seen that all the plates possess apophyses for attachment of the muscles, but the cephalic plate has none. Now, only one of the three plates has the apophysis awanting, namely, *Cordatus*, so that these facts together point, it seems to me, to *Cordatus* being the cephalic valve; *Gemmatus* the intermediate plates, of which there are six in each Chiton; and *Armstrongianus*, the anal valve.

Chitons go as far back as Ordovician; they are rare in Silurian and Devonian, but somewhat abundant in the Carboniferous. None of the Palæozoic genera is known to reach the Mesozoic, and of those species that have been described about twenty are Palæozoic, five Mesozoic, and fifty Tertiary.

Digitized by Google

Recent forms number several hundreds. Since the recognitions of the fossil species are mostly based on single plates, and since, as has already been stated, the Chitons possess three different kinds of plates, I am persuaded that if our knowledge were more complete the number of species would be considerably reduced.

To sum up the evidence on which I base the opinion that the plates found at Woodmill all belong to one and the same species—

(*a*) The number of plates found gives ratios very nearly *six* of Gemmatus to *one* of Armstrongianus to *one* of Cordatus.

(*b*) The microscopic structure is the same for all three species so-called.

(*c*) The plates are often found lying together.

(*d*) One of the plates has no apophysis, and a like condition exists among modern Chitons.

Certain shells are found in the Chiton bed that do not occur anywhere else in the Section, such as *Grammatodon geintzi* (De Kon.); *Mourlonia portlochiana* (De Kon.); a small Naticopsis and a small Loxomena of unknown species both undescribed. Since my last note I have also found a bone which Dr. Smith Woodward describes as a basal bone of the fin of a fish, probably Megalithys, and later I have found the scale of a Megalithys, and some small teeth, very likely of the same fish.

When all the species found in this section are described and named there should be over a hundred species recorded. The Section is composed of calcareous clay, which disintegrates when exposed to the air, and effervesces with acid. The clay is banded at intervals of a few inches with concretionary nodules showing septarian structure, and it is often between these bands that the fossils are found, which suggests that they may have been killed quickly.

Digitized by Google

No. V.—Burrows, Trails, and Tracks in Sandstone, Charleston, Fife.

By Robert Dunlop.

The most familiar markings known to the Scottish geologists may be said to be the Spirophyton, *Cauda-galli*, which is supposed to be the impression of a marine Alga, and which always indicates a position near the Main Limestone and the Hosie. The impressions here exhibited were found very near the same position, and I have found similar impressions on the shores at St. Monans; Kirkcaldy; North Berwick; and Charleston, all occupying practically the same geological position.

The rocks at Charleston are well adapted for the preservation of impressions of this kind, composed as the exposure is of layers of mudstone and sandstone alternating. Worms crawling on the mud left the track of their bodies, and the sand coming on top has taken sharp casts of the tracks. Worms that bored through the mud to sand lying below have left well-defined burrows due to the fine parting of mud carried down on their bodies.

In these impressions there are represented at least two sub-kingdoms, the *worms* and the *gasteropods*, besides the *algæ:* what the others represent it would be difficult to say.

In a paper by Sir J. William Dawson, of Montreal, read to the Geological Society of London, 1890, some impressions are described very similar to those at Charleston, but Dawson's specimens are Silurian, while mine are Carboniferous.

Mr. John Smith, in a privately printed paper in 1909, described in his Upland Fauna of the Carrick Old Red Sandstone many trails and tracks of unknown creatures, and, now that we have so many specialists working at the invertebrates, more light should soon be shed on the subject.

Digitized by Google

No. VI.—Notes on Four Nautili.

By Robert Dunlop.

The four species of Nautilus exhibited have not, so far as I am aware, been recorded previously for Scotland. They are not in the list for Fife compiled by Sir Archibald Geikie, nor in that of this Society, nor in any others than I have consulted.

The specimens have been examined and named for me by Dr. Wheelton Hind.

Nautilus (Discites) oxystomus.

This shell was first described by John Phillips in his "Geology of Yorkshire" in 1836, and the localities given by him are Florence Court, Enniskillin and Isle of Man. Frederick M'Coy also refers to it in his Carboniferous Limestone Fossils of Ireland, and it is mentioned in the Proceedings, Boston Nat. Hist. Soc., vol. xxii., page 293, 1883. Many other references might be quoted, but most of the occurrences are in Ireland. In the British Museum there is only one specimen, of unknown locality, although it is generally supposed to be from Ireland.

I have obtained three specimens of this shell from Woodmill, but all are badly crushed.

Nautilus (Cœlonautilus) multicarinatus.

This shell was first described by Sowerby in 1825, also by Phillips in 1834, who gave the localities Cork and Cumberland. In 1844 M'Coy, in his "Carboniferous Fossils of Ireland," describes it as *N. porcatus*, and it has been recorded from Belgium by Dr. De Koninck. The British Museum possesses some good specimens from Cork and Kildare, Ireland.

Nautilus (Solenocheilus) crassiventer.

The earliest mention of this shell occurs in De Koninck's "Carboniferous Fossils of Belgium," published in 1878. It is evidently a very rare shell in England, for it is represented in the British Museum by a solitary English specimen.

Digitized by Google

Nautilus (*Solenocheilus*) *cyclostomus*.

This species was first figured in 1834 in Phillips' Geology of Yorkshire. At that time it had been found at Castleton and High-Green-Wood. In 1878 De Koninck recorded it from Belgium, and the best specimens in the British Museum are from that country.

It has been found also in Ireland; England (Yorkshire); Russia (Ural Mts.), but, so far as I know, there is no previous record of it for Scotland.

Digitized by Google

No. VII.—An Example of River Action and its Bearing on Plant Distribution.

Donald Patton, M.A., B.Sc.

At the present day Geology seems to be more concerned with the Botany of a long past than with the plants that have not yet made their mark upon the world. The Rhynie fossils have thrown both Geologists and Botanists into ecstasies, whilst the hybrids—the Phyto-Geographer and the Agriculturist look on askance. Perhaps the reason for this contrast is due to Schimper and Axel Blytt, who held that soil has comparatively little to do with causing the characteristics of the vegetation of any region. In fact, it has been said elsewhere that it is *heat* that determines the flora of a country, *climatic humidity* the vegetation, and the *soil* as a rule only picks out and blends, and on its own account adds a few details. However that may be, I wish to-night to consider the Living Plant in relation to the Rolling Stone where both agencies are at work in altering the aspect of Nature.

In the Upper Ward of Lanarkshire, between the villages of Lamington and Symington the River Clyde has laid down a broad tract of alluvium through which it slowly meanders. It is here a " consequent " stream, the well-known point where it was captured from the Tweed by the young " obsequent " Clyde, is about a mile further down—at Culter Railway Station. As far back as 1904-5, when fishing that stream, I had my attention drawn to the rapidity with which erosion was going on in one of its meanders. As the stretch was a promising one for trout, I went there repeatedly, and the time spent in waiting for the gloaming rise was often spent in studying the results of river action. The angler, as he wades whilst fishing a stream, becomes acquainted with the configuration of the bed of the river, and is soon aware of any alteration that may have occurred in the direction of the current or that may have been brought about by corrosion. To him these are as obvious as is the erosion of the bank of the river. Geology, Botany and Angling go well together, for while the river exposes the rocks *in situ* the aquatic vegetation affords cover for the trout. Since 1904 repeated visits and observations have been made. Photographs have

Digitized by Google

been taken at the critical periods since April, 1911. In 1912 man first took determined steps to thwart Nature, and save from devastation the fertile holm within the meander. A retaining earth dyke had, as is usual in these parts, already been built much earlier around the holm, to stem the floods. But this was being burst through so often both at the N. and the S.W. angles of the meander that an erection of wooden piles was driven into the alluvium well back, at that time, from the water's edge, so as to direct the force of the flood-waters down the course of the river. But, though the interference of man protracted the struggle for mastery, it is now a long time since Nature overwhelmed human efforts. The once fertile alluvium is now silted and gravel strewn, and the remains of the frail erections of man hold him in derision.

Let us first look at the vegetation of the alluvium of this part of the Clyde Valley. For that purpose we will have to consider briefly the geological formation of the Upper Ward of Lanarkshire. The area under consideration lies just to the north of the Southern Boundary Fault of Scotland, which brings the Old Red Sandstone and Late Silurian down against the Silurian of the Culter Hills. Overlooking our meander from the north is the glaciated form of the Tinto Hills—an intrusive mass of Felsite which "has been injected into Downtonian and Lower Old Red Sandstone deposits underlying the volcanic platform of that period." This rock is in places massive and jointed, notably in the region of the road-metal quarry of Symington; but the usual appearance of it in exposures all over the hill is that of a brittle, flaggy rock, easily split. The build of this felsitic mass indicates what was mentioned in connection with the Arran intrusions by Mr. Tyrrell, that it has been formed not by one great injection, but by a large number of intrusions, which being injected as parallel sills, give the mass an interbedded appearance. The weathering of the Felsite plays a very great part in determining the vegetation of the Tinto Hills themselves; but as the whole Clyde Valley is flanked deep with Boulder Clay and as a considerable distance, as shown by the map, intervenes between the outcrop of Tinto and the alluvial plain, very little of the Felsite is distributed over the river banks. More,

Digitized by Google

perhaps, comes from the flushing of the roads during heavy rain than from the actual hills during a spate, for the roads in the district are metalled with the Felsite. However, the following table will indicate the poor nature of the contribution of the Felsite to the alluvium :—

	*S_1O_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	H_2O
Sol. in HCl, -	·04	1·01	1·24	·92	·52	—	—	·16	—
Insol. in HCl,	70·28	12·54	·43	·91	—	3·92	5·84	—	1·99

* "Ancient Volcanoes of Scotland"—*J. Geikie.* (Prof. E. Frankland). Vol. I., p. 278.

If, therefore, we examine the gravel of the river we find that the Felsite is very sparsely represented. It is to the rocks of the upper reaches of the Clyde chiefly Silurian that this gravel and also the alluvium are due. Not only does the gravel consist of rounded fragments of the rock formations past which the River Clyde and its tributaries flow, but also of the pebbles and boulders from the Boulder Clay which the water has eroded. Thus there are pebbles derived from rocks outwith the Clyde basin, but brought by the ice as it radiated from its centre of distribution. The pebbles are chiefly of volcanic origin, though very many consist of quartzite-pebbles from the Old Red Sandstone Conglomerates undergoing a second (or perhaps a further) existence under the sun. Now, as to the alluvium which is built up upon the river banks and the gravel as it merges into the soil of the river banks. Floods are frequent, and abundant sediment is brought down by the current. As much of this sediment is derived from the weathering of the trappean and other volcanic rocks as well as from the Boulder Clay of the upper reaches of the Clyde, the rich alluvium so formed has caused the Valley of the Clyde to be noted for its fertility for generations.

An important factor in connection with the river action lies in the climatic conditions. The following are the mean monthly and annual rainfall records for twenty-five years (1866-1890), which have been recorded at Douglas Castle :—

January, -	5·37 ins.	July, -	3·65 ins.
February, -	3·94 ins.	August, -	3·83 ins.
March, -	3·35 ins.	September, -	4·17 ins.
April, -	2·31 ins.	October, -	4·46 ins.
May, - -	2·52 ins.	November, -	4·64 ins.
June, - -	2·43 ins.	December, -	5·01 ins.

Average annual 45·68 ins.

Digitized by Google

The rainfall is higher in the hilly regions to the S. and S.W. The prevailing wind is S.W. It is seen from the above tables that the greatest rainfall is in the winter months, and the heaviest flooding usually takes place then, although during the Lammas Floods the river often rises high enough to extend over the alluvium, from Boulder Clay to Boulder Clay in places, and the area under consideration is a case in point. Further, these floods often descend quite unexpectedly and with great rapidity. There may have been no rain in the Symington area, but the head-waters may have been experiencing a heavy precipitation. This is a feature which the River Clyde has in common with the Tweed, and for the same reason. We are all familiar with this, from the graphic account of a spate on Tweed by Dr. Buchan in "John Burnet of Barnes." In such circumstances the havoc wrought by the river is very great. Nevertheless Nature works through all with a characteristic slowness, but with great determination. This will be seen in our example of river action.

Let us next consider the vegetation of this area, and in that connection let us glance briefly at the progress of agriculture in the Upper Ward of Lanarkshire, for the natural conditions of the vegetation of the haughs and holms of the Clyde have been altered by the influence of man. Prior to the Roman occupation of the district there was little or no cultivation of the soil. "The Romans left the people in a much more improved state than they found them. From being hunters they had advanced to the state of graziers"; and grazing continued to be carried on by the inhabitants for a long time before any attempt was made at tillage. By the 14th century much corn was grown, and less barley, pease and beans in small quantities, and lint; whereas rye was scarcely cultivated. The pasturage consisted of natural grasses. It was not until the end of the 18th century that there was any attempt made to grow turnips in the vicinity of Tinto. "According to Naismith's computation," 1798, "between two-thirds and three-quarters of the Upper Ward of Lanarkshire is occupied by hill or moorland, not capable from the elevation of the country of much agricultural improvement, but forty-two years have produced great improve-

Digitized by Google

ments in cultivation and soil." Until 1770 there was no sown grass in the parish of Symington, and until 1780 no turnips were grown. Their introduction was due to a " Major Telfer who, on retiring from the Army, in order to amuse himself and advance the happiness of mankind." I'm quoting

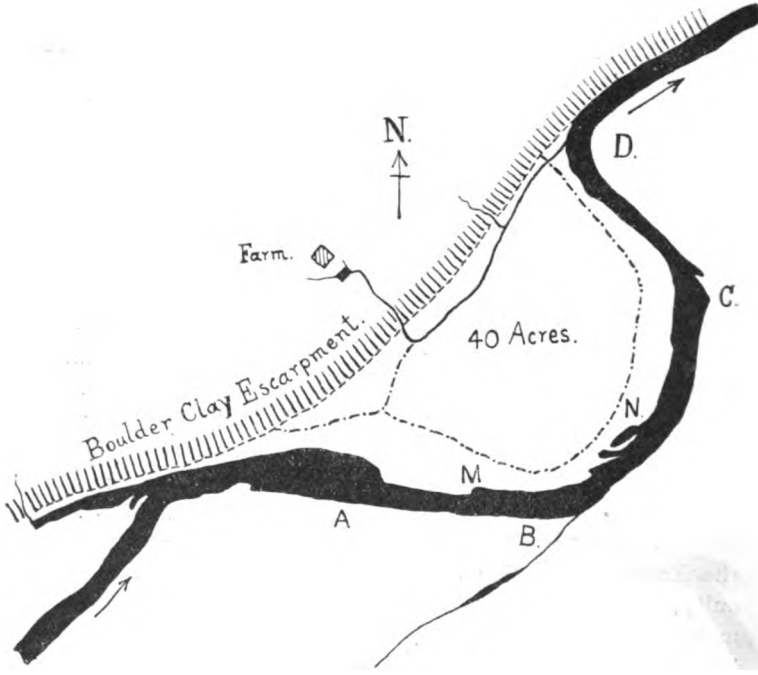


Fig. 1.—Taken from Survey Map. Surveyed in 1859. Published 1864. Shows an earlier stage in the history of the meander.
Black indicates the river channel—gravels included.
Scale—4·23 inches to 1 mile.

from the statistical account of Scotland, " took a lease from his brother of 100 acres of the most useless part of the estate wholly covered with broom and let for a sheep walk. In the space of six years this barren field was made to produce excellent crops of corn, turnips, and hay." One result of the introduction of turnips growing was the eradication on a large scale of the weeds of the farmyard. In earlier years, according to accounts, it was sometimes impossible to harvest a crop—so upgrown was it with weeds. We come now to the year

Digitized by Google

1845. Again quoting, " The principal part of the arable land in this part of the county lies in the parishes around Tinto *along the side of the Clyde*. The alluvial soil of the meanders is of the nature of carse ground and is exceedingly fertile."

But the great advance of agriculture really dates from

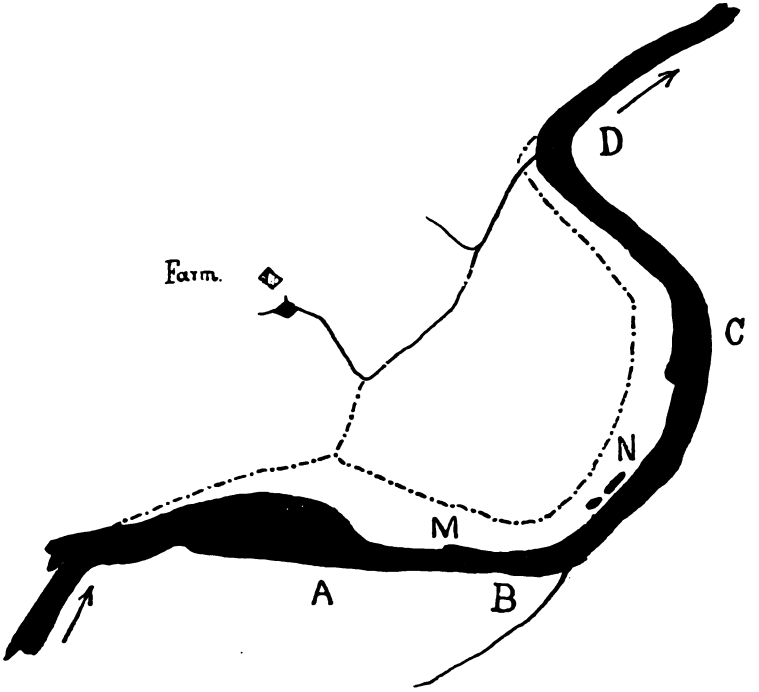


Fig. 2.—Condition of meander in 1908.
Scale—4·23 inches to 1 mile.

the first appearance of the Turnpike Roads (enacted 1755), and agriculture improved as the roads, *e.g.*—In Thankerton in 1793, 630 acres were under tillage; in 1840, 2000 acres. Since that time improvements have continued, and with the liming, manuring and draining, and with the rotation of crops, not only the alluvium but the adjacent Boulder Clays have become more fertile. But there is a limit, and that is chiefly determined by the climatic conditions. Lack of sunshine, the prevalence of mists, these considered along with the stiffness of

Digitized by Google

the soil and its water-content in relation to the spring and autumn temperatures prohibit the successful growth of wheat. Barley thrives better. Oats, however, is the chief grain cultivated in these parts.

Such remarks then give some idea of the factors at work on the alluvium of the Clyde Valley, and the meander we have under review was considered, prior to the ravages made upon

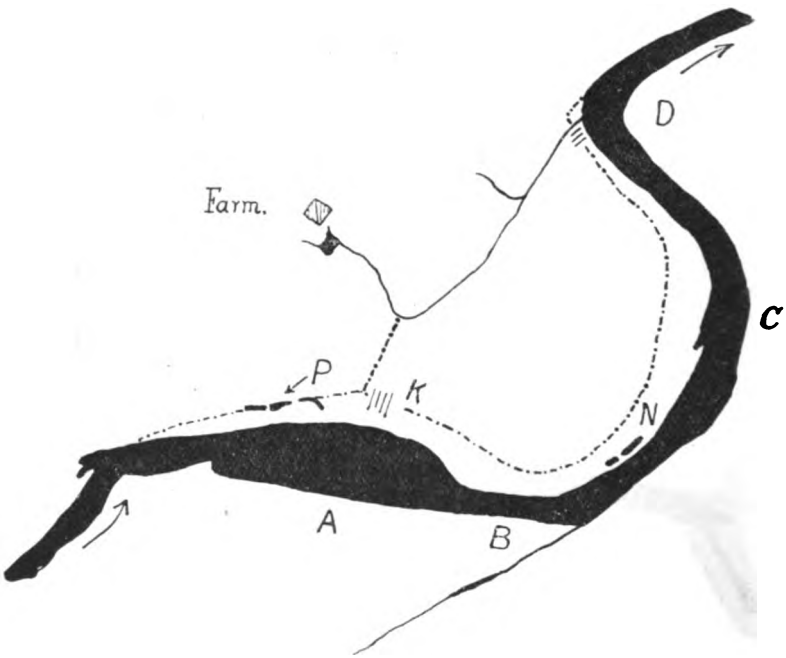


Fig. 3.—Condition in 1912.
Scale—4·23 inches to 1 mile.

it by the river, to be one of the most fertile holms in the district. Its yield was marvellous—the talk of the surrounding farmers. Now, as to the inter-relations of the river and the alluvium. After all it is a game of Take and Put—a much older game than the one at present in vogue. Above our meander is an extensive area of gravel. Its barrenness points to the rapidity of erosion lower down, as well as to the relative absence here of corrosion. As erosion has continued the advance of this gravel tract has gone on. The colonising of

Digitized by Google

the gravel from the adjacent alluvium with vegetation is as interesting as is the gradual transition from gravel to alluvium. But we shall not touch on that here. Fig. I. shows the course of the Clyde in 1859, Fig. II. in 1908. XY is escarpment of the Boulder Clay—marking a previous bank of the

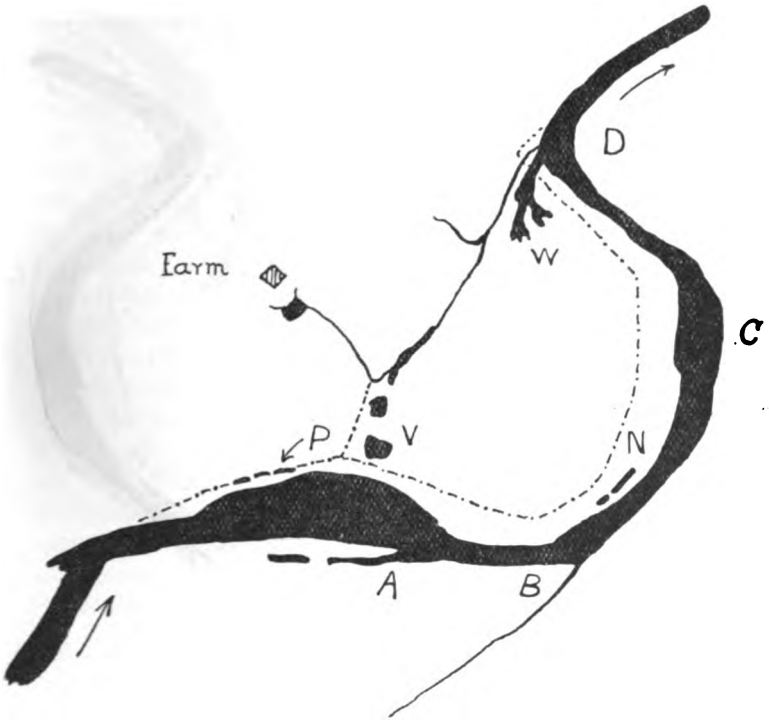


Fig. 4.—Condition in 1916.
Scale—4·23 inches to 1 mile.

Clyde; M and N are the remains of old river courses, pools of an older period when the course of the Clyde ran that way; AB is the protecting earth dyke; C an automatic sluice on ditch. As erosion continued so did the continual down creep of gravel, so much so that the bed at AB tended to be raised. Thus was the assault on K increased.

To meet this a row of wooden piles, Fig. III., was driven in 1912 at P, the intention being to direct the current into its

Digitized by Google

former channel. There was always a menace here, for there was the possibility of the current being directed against the opposite bank, where there was a similar holm also dyked off to protect the land within from floods. However, Nature prevailed. The retaining turf dykes were repeatedly burst both

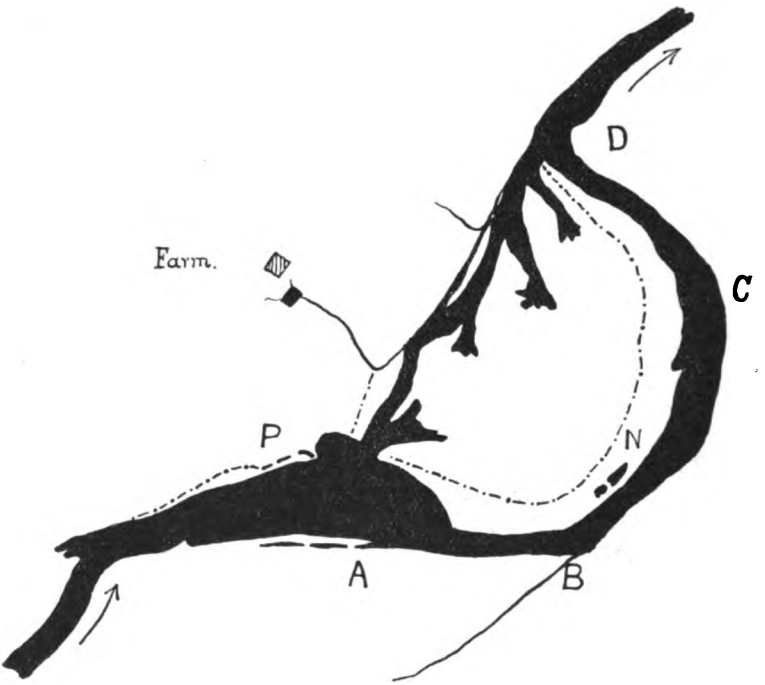


Fig. 5.—Condition in 1921.
Scale—4·23 inches to 1 mile.

above and below the holm fields, and concrete was even used to give them some power of resistance, but all in vain. Ultimately they ceased to be repaired and a condition such as is shown in Fig. IV. obtained.

Note that the dykes have been laid low at V and W, and corrosion has commenced within the area at these two points. There was a ditch flowing from the Mains Farm and entering the Clyde at D. This was provided with a sluice where it passed under the earth embankment to prevent the flood-

Digitized by Google

water from rushing back up into the enclosed area, and it worked all right so long as the dyke held. This ditch, as is usual, had toughened its bed, so that when the river commenced to corrode its new course it cut into the alluvium, finding it easier, and the ditch for a time persisted as such in dry weather.

At V pseudo pot holes were formed of great depths. The grinding was quite audible. Now, why did the river take this new course? Fig V. This is better understood if we consider the Clyde in spate. The gradient AD is greater than that at AB, BC, CD, but the difference is augmented as indicated above (*i.e.*, by the raising of the bed in the pool lying between A and B). Hence in flood times the main volume of the water flowed direct from A to D, causing greater corrosion and erosion *en route*.

At the present time the new course is practically completed, though a considerable volume of water still follows the meander when the river is low.

Now, what has happened to the vegetation?

When the securing of crops became uncertain latterly on account of flooding—the embankment not being repaired—the holm was given over to pasturage and for a few years produced luxuriant vegetation, excellent grazing, as rich and sweet as the alluvium of the river banks without. The common ragwort soon proclaimed that fact. The following is a list of the characteristic plants found growing there:—

(On the drier parts.)

Senecio Jacobæa,
Scabiosa Succisa,
Rhinanthus Crista-galli,
Trifolium pratense,
T. repens,
Ranunculus repens,
R. acris,
Bellis perennis,
Lotus corniculatus,
Anthoxanthum odoratum,
Cynosurus cristatus,
Thymus Serpyllum,
Alchemilla vulgaris,
Cnicus arvensis,
Achillea Millefolium,
Prunella vulgaris,
Plantago lanceolata,
Rumex spp,
Conopodium majus,
Luzula campestris,
Agrostis tenuis,
A. alba,

And one or two weeds of the arable land and a few more grasses which still persisted.

Digitized by Google

(On the wetter parts.)

Senecio aquaticus,	*Mentha aquatica*,
Ranunculus Ficaria,	*Myosotis palustris*,
R. flammula,	*M. cæspitosa*,
R. repens,	*and species of*
Caltha palustris,	*Juncus*,
Viola palustris,	*Carex*,
Spiræa Ulmaria,	*Equisetum*,

Chrysosplenium oppositifolium.

The cattle were the first to notice a change in the vegetation of the enclosed area. Shunning it and making through the gaps in the dyke, for the grassy holms of the riverside. The herbage was, with each flood, laid by silt, but ultimately the more rank species of grass and sedge grew up and flourished. Ranunculus repens, from being a frequent plant became dominant. Marsh plants from the quondam ditch invaded the area, and Juncus communis and Equisetum palustre sprang up everywhere. Polygonum amphibium, which was unknown within the meander previously, but which grew abundantly farther up the river established itself at one or two points and spread rapidly. Thus we have seen the development of a marsh association. There is, at the newly-made entrance, a fan of gravel now densely grown with Mimulus Langsdorfii, Caltha palustris, Rumex crispus and Cnicus arvensis. Ranunculus repens is encroaching upon it from the silted soil. Many of these plants have doubtless been washed down entire from some eroded bank, left stranded and able to continue their growth. As the new channel of the Clyde at this point becomes more and more established this marsh will gradually become drained and once more a fresh alluvium flora will displace the marsh associations.

Digitized by Google

No. VIII.—The Parallel Roads of Loch Tulla.

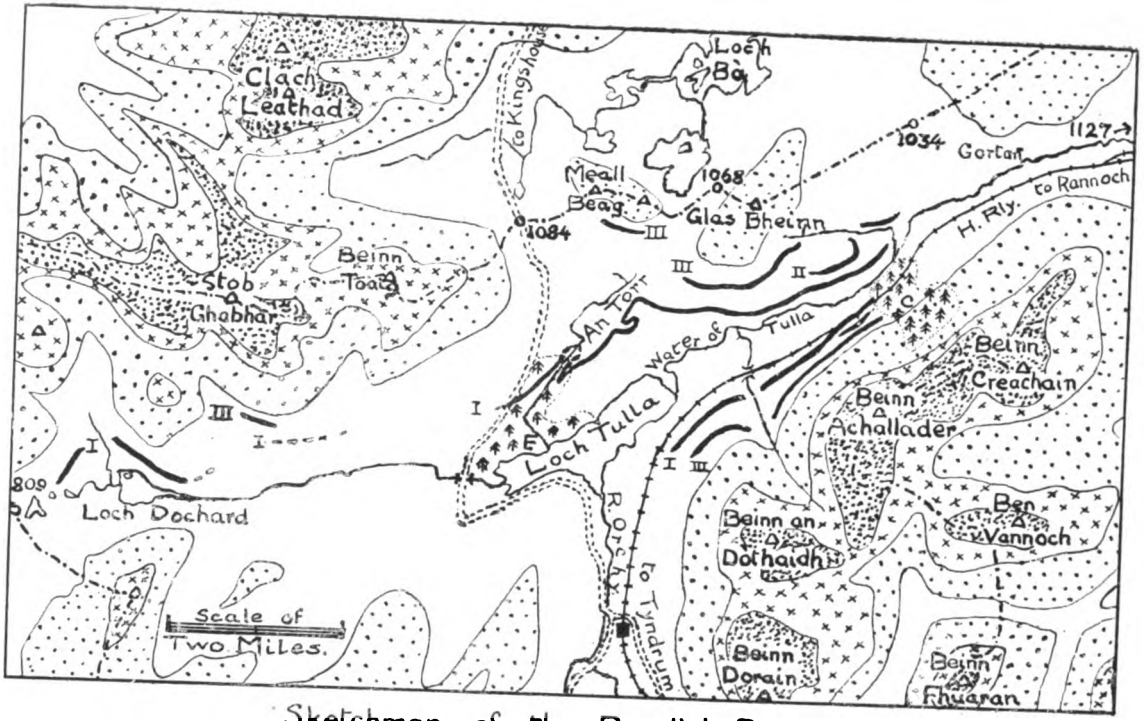
J. C. Gregory, B.Sc.

I. Introduction.

The Parallel Roads of Glen Roy, for long a mystery to men of Science, have received so complete and natural an explanation, due especially to Macculloch, Agassiz, and Jamieson, that one was led to wonder whether water might not have been impounded by ice in a similar way elsewhere in the Highlands, with the formation of similar beaches. Many cases occur of alluvium laid down by glacial lakes, sometimes with the formation of low terraces, but hardly any high level beaches have been traced out comparable with those of Glen Roy. While passing along the west Highland line between Tyndrum and the Moor of Rannoch and along the road from Bridge of Orchy to Kingshouse, Professor Gregory had several times noticed three such terraces, and found beach material upon them. He suggested that I should determine their height and extension, and I had the opportunity to do so in April of 1921. During the very next month, Messrs. John Mathieson and E. B. Bailey undertook the same operation. With the exceptions referred to below, our work is in agreement, but as they used a theodolite the heights they obtained by triangulation must be accepted as far more nearly correct than my aneroid observations. Their results have been presented to the Geological Society of Edinburgh.

Loch Tulla lies 8 miles N.N.W. of Tyndrum (see Fig. 1). It is a small loch surrounded by hills rising to a general level of 1500 feet with several points over 3000 feet. The mass of the Black Mount lies to the N.W., and the range containing Ben Achallader to the E. and S.E. The loch overflows southwards to the River Orchy, which runs for a few miles among numberless moraine

Digitized by Google



Sketchmap of the Parallel Roads.

"Roads" III II I
Watershed of R. Orchy
Cols, height in feet, --o 1034.

Hill summits ..... △
C = Crannach
F = Forest House

Ground over 2500'
" " 2000'
" " 1250'
" under "

Digitized by Google

heaps before entering Glen Orchy. The following are the only passes under 1240 feet:—

1218 feet,	S.E.,	To Loch Lyon.
1127 ,,	E.N.E.,	Railway to Rannoch.
1084 ,,	N.,	Kingshouse Road.
1068 ,,	N.N.E.,	To Loch Ba.
1034 ,,	N.E.,	To Loch Laidon.
1043 ,,	S.S.E.,	Road and Railway to Tyndrum.
809 ,,	W.,	Beyond Loch Dochard.

Had, then, ice filled Glen Orchy, a considerable number of other outlets would have been available, and it is not likely that they would all have been blocked by ice until after the clearing of Glen Orchy.

These figures are taken from the 6-inch Ordnance Survey maps of the district, 1900 edition. The spot-levels used appeared to me to be situated so close to the lowest points on the watershed that I made no attempt to verify them on the ground, but after visiting the Loch Ba Pass Messrs. Mathieson and Bailey consider that a channel exists there slightly lower than any leading across to Loch Laidon.

2. Nature of the Terraces.

The old beaches are only found N. of a line from the S. end of Loch Tulla to Loch Dochard, and they are most conspicuous around its N.E. end. There are three series, viz., at 816, 930 and 1030-1150 feet. The lowest one is the most perfectly developed and it can readily be traced. The intermediate one occurs over only a very short distance. The upper series consists of a triple terrace formed of three beaches quite close together, and indefinite except when seen from some way off, while above it are faint relics of two earlier lines.

The hillsides are covered with morainic mounds, across which each terrace cuts, forming a small ledge. These ledges vary in breadth from a few feet up to 20 or 30 yards; their slope is commonly about 10° on a hillside sloping at 20°. The moraines generally have flat or rounded tops, but they are local, and although several mounds may often be found together with their tops at nearly the same level, they appear only as projections from the hillside, and the shelf thus formed does not curve into re-entrants. The terraces,

Digitized by Google

on the other hand, follow round the moraine mounds and give the appearance of being completely later. (See rough sketch, Fig. 2).

Broad morainic shelves are common, sometimes up to 150 yards wide, and either sloping gently or else flat. They may run along the hillside for a considerable distance, but seldom keep level longitudinally.

Although the terraces are difficult to see from close at hand, and are often invisible, yet they appear distinct from a distance. They are best viewed from their own height at a

Fig. 2.—"Road" on Spur of Beinn an Dothaidh. Looking across Loch Tulla from Budha Ghall. Ben Achallader seen beyond. Terraces about 1 mile distant.

quarter to one mile away, as when looking across a valley. If the light is directly down on them, no shadows are cast, and the best time of day to see any particular hill slope is when the shadows are longest, but most nearly downhill. They are seen as very faint horizontal lines running among and across the moraines with frequent interruptions, but appearing again at the same level further on. (See rough sketch, Fig. 2).

If a terrace has to be seen at close quarters, it is best observed from below. While describing the roads in Glen Roy, Macculloch wrote (1824, p. 345): "In one most essential

Digitized by Google

circumstance, they bear no resemblance to roads, inasmuch as they are not level or flat; the angles of their deviation from the horizontal plane varying from 12° to 30°, in which last case they are scarcely distinguishable from the slope of the hill on which they lie. Hence it is that they are sometimes invisible, or nearly so, except from below, where the shadowy line produced by the foreshortening, renders them apparent. When we are on the same level, so that they are prolonged from the eye, and when we look down on them, we often cannot see them at all; and even when on them, it is frequently very difficult to be aware of it, far less to suppose that we are standing upon a road. Where widest, they are about 70 feet in breadth and from that they vary to one as low as 10 or 12, 50 or 60 being perhaps the most common dimensions. . . . ."

Finally, we may quote Jamieson (1892, p. 17): "These 'roads,' although wonderfully clear when viewed from a distance under favourable light, are nevertheless often very obscure when we come to stand upon them. Sometimes, indeed, they seem to vanish altogether in ghost-like fashion, so shadowy and vague is the outline of what remains."

Some shingly material was found on the terraces, consisting of subangular pebbles of 2-inch diameter downwards. Many showed signs of subærial denudation in position, *e.g.*, pebbles of garnetiferous mica schist having the garnets left as projections. These pebbles greatly resemble the shingle just above the present water level of Loch Tulla in both size and shape, and they are distinct from the material of the moraines.

3. Distribution of the Terraces.

Lowest Terrace.

This is the most clearly marked of the terraces, and it is not difficult to find. My observations by aneroid barometer gave its mean height as 830 feet, while Messrs. Mathieson and Bailey give 816 feet. These observations may be taken as being in agreement, but the lower figure may be adopted as the more nearly correct. My height cannot be relied on to 14 feet. The beach appeared quite level to the eye, but it would require a surveyor's level or a theodolite to test this further.

Digitized by Google

The terrace cannot be seen on Ben Dorain, but it appears on Ben Dothaidh. It is perfectly distinct on Ben Achallader, but where it crosses the dividing ravine, Allt Coire Achallader, it is not clear. There is here a broad gently-sloping platform triangular in plan, which has been cut through by the burn. The upper edge is near the level of the terrace. The vertex is 130 yards from it and about 20 feet below it. The section in the railway cutting consists of washed and rounded morainic material. Three feet of finely laminated clay rests in a small channel on the top of it.

There appears to be no other explanation of this platform than that it is a delta pushed out into Loch Tulla, while the 816 feet beach was being formed. It does not resemble a normal delta in its slope of over 3°, and the coarseness of most of its material, but its conditions of deposition must have been unusual. The melting snow in Coire Achallader would have supplied a large flow of water which would have been able to carry down material up till then held back by ice. A steep gradient was continuous down to and below the water level, and when sediment was rushed into the lake it would naturally lie at some angle determined by the force of the flow, with its front sloping at the angle of repose. The slope cannot be accounted for by rain wash, for the first consequence of this agent would be to round off the lower edge, instead of leaving it perfectly sharp as at present.

The terrace is well marked as far as Crannach, and it is crossed by the railway line before entering the wood. It reappears on the N.W. side of the Water of Tulla, passing along the foot of Glas Bheinn. An old delta similar to that of Allt Coire Achallader, but less complete, occurs W. of the wood. It is cut through by both the Water of Tulla and by Allt na Coille Bige. Sections in it show that it consists of fine sand with hardly a trace of bedding. On either side of it is normal morainic material. It is interesting to note the stretch of sand about 200 yards wide at the N.E. end of the present loch, which is half a mile broad. It illustrates the manner in which the above sand must have accumulated.

After passing along Glas Bheinn, the beach follows close to the top of the long low ridge of An Torr. It curves round the

Digitized by Google

S.W. end and runs back for a short distance along the N.W. side before crossing Allt Bhreacnais and resuming its south-westerly direction. It is traceable through the woods of Forest House, but it is difficult to be sure about it in the wood, and it disappears after crossing the road S.E. of Ben Toaig. A " road " at about the right height lies N. of Loch Dochard, and it is very distinct. It curves round so as to aim for the pass into Glen Kinglass, but I had no opportunity of tracing it carefully nor of following it to the divide.

The outlet to Glen Kinglass is at 809 feet according to the Ordnance Survey 6-inch map. A chain of lochans rises gently from Loch Dochard to close up to the col, but once over it the ground falls much more sharply.

Intermediate Terrace.

This is found only to the E. of Glas Bheinn and on the N.W. slopes of Ben Achallader. The S. end of the former sends out a long spur to the E., bounded to S. and E. by the Water of Tulla, and to the N. by Allt Coire Seilich. A terrace which occurs on the E. end of this spur may be traced to the S.W. to above the house Barravurich, and for some distance to the N.E. Its mean height is 930 feet + or − (25 feet). It is quite distinct, but can be recognised over only a surprisingly short distance.

The hill slopes immediately opposite are covered by the wood of Crannach, and no distinct traces of the terrace could be seen to the south of the wood, from some distance off. But it was recognised in some measurements taken on Ben Achallader, half a mile to the N. of Allt Coire Achallader.

No pass exists out of the basin at a height between 809 feet and 1034 feet. It must therefore be assumed that some ice barrier occupied the Loch Dochard gap up to this level. While the fact that Messrs. Mathieson and Bailey did not observe any terrace in the above position throws additional doubt on the existence of one, the line described above seemed to me to have the appearance characteristic of these " roads," although fainter than the adjacent ones.

Upper Terraces.

They are only conspicuous at a distance, when a triple

Digitized by Google

terrace consisting of three or sometimes only two faint parallel lines may be seen. When search is made close at hand nothing so definite is found. For a height of about 120 feet the hillside slopes more gently than usual, and along this shelf run a number of beaches. The triple one is the lowest, at about 1030 feet. Higher up obscure traces of two more terraces may occasionally be visible at heights of about 1090 feet and 1150 feet. It must be insisted, however, that these are approximate measurements only, as the barometer was constantly fluctuating, surveyed heights were scarce, and the setting was seldom known more closely than to 20 feet. As I did not make a sufficient number of observations, I have not shown the two higher terraces on the sketch map.

Messrs. Mathieson and Bailey give the heights of the components of the triple terrace as 1020, 1030, and 1041 feet. They do not record any higher ones.

As in the case of the lowest terrace, these upper ones are not found on Ben Dorain, but beginning on Ben Dothaidh pass along Ben Achallader into the wood of Crannach. On the hill N. of Gorton only traces are found, but they are quite distinct on the S. and E. sides of Glas Bheinn. Between the two is a mile of flat moorland, which forms the divide between the Water of Tulla and Loch Laidon, and as a slope is necessary for the formation of the terraces, none are visible on it. I did not see any on the W. side of Glas Bheinn, but they are found on the S. side of Meall Beag. The shelf which runs up the W. side of the latter does not seem to be a beach.

While the terrace is absent from Ben Toaig, it occurs on the S. spur of Stob Gharbhar, and there are further indications to the N. of Loch Dochard. I was unable to trace them in detail.

The best view of the terraces from the train is obtained between the head of Loch Tulla and the wood of Crannach. Just before entering the wood, the railway line crosses the terrace, and the complete series is glimpsed across the valley. The higher ones are seen best near the viaduct over Allt Coire Achallader. It is a waste of precious time to look for any beaches on the same side of the valley as the train, but to do so illustrates their invisibility at close quarters.

Digitized by Google

4. Origin of the Terraces.

No explanation other than that of a glacial lake seems able to account for the terraces described. So far as the eye can test them, they are perfectly level; they are distinct from and later than the moraines; their height and distribution may be explained by this theory; and lastly, looking at a map of the region we might anticipate them. To disbelievers in the beach theory for Glen Roy there is here no proof as convincing as in the historic case. The roads are less obvious and less readily explained. But once the theory is admitted in Glen Roy, it seems impossible to doubt it for Loch Tulla.

When the ice was at its maximum, it is generally believed that nearly all Scotland was buried beneath the ice sheet. As it melted and the hilltops appeared, the ice was forced to move down the valleys, which it troughed, and in which it deposited quantities of moraines. The next stage must have been the gradual retreat of the front of these valley glaciers and their becoming thinner. Had this process been perfectly regular, no lakes would have formed, but as pointed out by Jamieson, the rainfall is at present very irregular, the snowfall was also irregular, and the higher and more south-westerly districts secured the greater amount of food for their glaciers. They therefore must have lasted longer than the ice less favourably placed.

Loch Tulla lies at the S.W. corner of the Moor of Rannoch, where for 10 miles square only one hill rises to 2000 feet. To W., S., and E. of the loch lie great masses above 2000 feet, and the snowfall on them, especially on their S.W. slopes, must have been heavy. Ben Dorain was very favourably situated as a snow-catcher, and the only convenient outlet for its glacier was down Glen Orchy. As the latter is long and deep, and passes among 2000-feet hills, it would be blocked until a late stage in the glaciation, and certainly till after the ice had left the Moor of Rannoch. Water would therefore be confined to the E. by Ben Achallader; to the S., by ice running from Ben Dothaidh to Ben Inverveigh; to the W., by ice from Stob Ghabhar and Stob Coir an Albannaich flowing down Glen Kinglass to Loch Etive; to the N.W., by Ben Toaig; and to the N., by the line of low hills, Meall Beag and Glas

Digitized by Google

Bheinn, reinforced by any ice on the moor. As the latter ice melted four outlets became available, and the overflow must have been by one of these to Loch Rannoch.

The pass farthest W., at 1084 feet, on the Kingshouse road, must have been stopped on the N. side by ice from Ben Toaig and the Clachlet (Clach Leathad), until after one of the two central ones was clear. As the latter are both below 1084 feet the pass at that height may be left out of consideration. The same need not be true of the pass used by the railway, as it is separated from the hills to the S. by a couple of miles of gently sloping ground, and ice might have been able to flow away to the N. or S. without much passing over it. The three available outlets, from E. to W., are therefore—1127 feet close to the railway N. of Gorton Crossing; 1034 feet N.E. of Glas Bheinn; 1068 feet between Glas Bheinn and Meall Beag. If the faint marks at about 1150 feet and 1090 feet really are terraces, each one corresponds to a pass, thus—

Terrace.	Pass.	Difference.
1150 feet.	1127 feet.	+ 23 feet.
1090 „	1068 „	+ 22 „
1030 „	1034 „	− 4 „

Apart from the liability of these heights to error, I cannot assert that the two upper gaps have been outlets, owing to lack of a sufficient number of observations.

For the triple terrace, we may accept Messrs. Mathieson and Bailey's heights of 1041, 1030, and 1020 feet. The two upper heights must be due to the 1034-feet pass, or to an adjacent outlet over the same broad flat area. The lowest one may have the same origin, although it is hard to believe that the outlet has been raised 14 feet since glacial times by the growth of peat and by rain wash. Messrs. Mathieson and Bailey attribute the two higher members of the triple terrace to two closely adjacent outlets at and west of what I here call the 1034-feet pass. They suggest that the level of this pass has been slightly underestimated by the Ordnance Survey—a "spot level" is admittedly an approximation—and that the pass corresponds to their 1041-feet terrace. For their 1020-feet pass they think they have found an outlet 400 yards

Digitized by Google

W.S.W. of the "spot-level" marked 1068 feet on the Ordnance Survey 6-inch map. If they are right in this matter, it seems impossible to ascribe my 1090-feet terrace to the 1068-feet pass as is done in the table just given, but the authors mentioned do not claim any certainty for their suggestion.

As to the order of opening of these passes, it would be controlled by so many factors that one cannot decide it on a map. The order required appears reasonable, but one can say no more.

The formation of the intermediate terrace at 930 feet must have been due to a partial opening of the Dochard Gap and by an outflow over the ice at that height. That this level did not last for long is shown by the lack of a greater extension of the beach, but I can find no clue as to why it remained constant for long enough to make even as much of a mark as it did. One would expect the level of the water to have fallen slowly and irregularly, but it is surprising to find evidence of so marked an arrest, which extends for so short a distance.

The lowest terrace is the most complete and it is readily explained. Ben Dorain continued to keep the Orchy filled with some 400 feet or more of ice while the flow from Stob Ghabhar decreased in amount and did not pass over the divide. The water must have stood at this height for a very considerable time, judging by the clearness of the beach, although not as long as in any of the cases in Glen Roy. The N. shore of the old lake is well indicated, as described above, but absence of any conspicuous sign of the S. shore suggests that the hills on the S. side were still ice covered, so that the water did not lap against drift.

It may be noted that the highest terraces are the oldest, and also the faintest, as one might expect.

5. Movement of Ice.

The foregoing explanation requires the fulfilment by the ice of the following:—

(1) The opening of the Dochard Gap before Glen Orchy.
(2) The absence of ice from the hillsides at points where the terraces are found.

Digitized by Google

(3) The freeing of the 1127, 1068, and 1032 feet outlets in that order.

(4) The clearing of the 1068-feet pass before or soon after the one at 1084 feet.

Of these points, three were almost inevitably fulfilled, while there is no valid objection to No. 3.

6. Passes.

On the passes to the N. there are no large water-cut channels, but as the ground slopes only very gently in all directions this is natural. The escaping water passed off with low velocity over a wide bed, and was not confined to a narrow channel. As Jamieson says (1892, p. 15): " . . . water issuing out of a lake over level ground has no power to cut a trench. . . . A river passing over a wide flat surface tends to accumulate sediment rather than to cut into its bed; it is only when it has gathered speed and come to a good trot downhill that it begins to cut. . . . "

In addition, the lake acted as a settling tank for sediment and the discharged water was too pure to be able to cut a gorge. The green slime on the sill of Niagara is an oft-quoted example of this comparative powerlessness of water issuing from a still lake to corrode its bed.

7. Comparison with Glen Roy.

The case of the " roads " near Loch Tulla is more difficult to treat than the historic case, as in the latter the roads are better marked. The reason for the greater duration of the Glen Roy lakes is that the ice must have retreated more slowly there, as the Ben Nevis group is so fine a collecting ground for snow. The abundant deltas of Glen Roy are represented only by two cases near Loch Tulla. In Glen Roy, there appears to be little confusion between morainic ledges and the " roads," while at Loch Tulla differentiation is not always easy.

8. Conclusion.

There can thus be no doubt that during the retreat of the ice the district around Loch Tulla was occupied by a lake, which was lowered by two minor and at least three major

Digitized by Google

stages, forming beaches during each pause. This occurrence suggests that still other lake series may yet be found in the Highlands by any one who has the time to visit areas where they are probable, and the inclination to tramp over hillside and through peat swamp in pursuit of a phantom terrace, which will fade away as soon as it is approached. Much may be done in confirmation or otherwise of the foregoing, especially the more accurate surveying of the "roads" and further determinations of their extent. To do so in great detail would prove a tedious process, and perhaps not worth the trouble. As to the height, the accuracy obtainable with the best of instruments is not great, for as Sir Thomas Dick Lauder pointed out (1821, pp. 6 and 7): "It is indeed impossible to perform a mathematically accurate levelling process on such rude and indefinite subjects as these shelves are." Seen from a distance, sometimes the lower edge of the terrace is the more conspicuous, sometimes the higher. An error of 5 feet in level would therefore be of little consequence, as the height of the upper edge above the lower may easily be 10 feet.

I have to express my obligations to Professor Gregory, under whose direction the field work was performed and the results interpreted. This paper is little more than the record of an approximate survey of lines pointed out by him, while most of the conclusions were suggested or accepted by him. I am very grateful to Messrs. Mathieson and Bailey for giving me the full benefit of their work, and for the more exact determinations of the heights.

Digitized by Google

REFERENCES.

Agassiz, L.
1842. "The Glacial Theory and its Recent Progress."—*Edin. New. Phil. Jour.*, vol. xxxiii., pp. 236-240.

Dick, T. L.
1821. "On the Parallel Roads of Lochaber."—*Trans. Roy. Soc., Edin.*, vol. ix., pt. I., pp. 1-64 with plates.

Jamieson, T. F.
1863. "On the Parallel Roads of Glen Roy, and their place in the History of the Glacial Period."—*Q.J.G.S.*, vol. xix., pp. 235-259, and plate x.

1892. "Supplementary Remarks on Glen Roy."—*Q.J.G.S.*, vol. xlviii., pp. 5-28.

Macculloch, John.
1817. "On the Parallel Roads of Glen Roy."—*Trans. Geol. Soc.*, vol. iv., pt. I., pp. 314-392, with plates.

1824. "The Highlands and Western Isles of Scotland."—Vol. i., pp. 339-355.

Mathieson, John, and Bailey, E. B.
"The Glacial Strand-lines of Loch Tulla."—*Trans. Geol. Soc., Edin.* Not yet published.

Digitized by Google

No. IX. — The Physical Conditions under which the Deutozoic Rocks of Scotland were Deposited. Part I. The Old Red Sandstone. By Prof. Peter Macnair, F.R.S.E., F.G.S., President of the Society.

I. Introduction.

In the course of my occupancy of the Presidential chair I hope to direct your attention to the present position of our knowledge regarding the physical conditions under which the Deutozoic Rocks of Scotland were deposited, that is to say, the conditions that prevailed during the formation of the rocks known as the Old Red Sandstone, Carboniferous and Permian formations. I also hope to be able to show that, notwithstanding the apparent lithological and palæontological differences that exist between the Scottish Old Red Sandstone and Carboniferous Formations, that upon closer examination a somewhat striking parallel can be drawn between the two types of sedimentation characteristic of the Devonian rocks of the British Isles and the two types characteristic of the Carboniferous rocks of the same area. In fact, it seems quite clear to me that the marine type of the Devonian as developed in Devon might be regarded as analogous with the marine phase of the Carboniferous rocks as developed in the British Isles, while, on the other hand, the Old Red Sandstone type of the Devonian as developed in Scotland and along the Welsh border might be regarded as analogous with the estuarine phase of the Carboniferous rocks as developed in Scotland and England. But an examination of this proposed comparison will be deferred till next session, when we come to a consideration of the physical conditions under which the Carboniferous rocks of Scotland have been accumulated.

II. Pre-Old Red Sandstone Continent.

Before passing to the more immediate subject of this address let me glance at the available evidence bearing upon the character of the pre-Old Red Sandstone platform upon which the later Palæozoic Rocks of Scotland are seen to rest with a strong unconformity. These rocks constitute what are geologically known

Digitized by Google

as the Crystalline Schists of the Highlands. They stretch from the Highland border north-eastwards to the Moine thrust plane which has been traced from the eastern shore of Loch Erribold S.S.W. to Loch Alsh. From this thrust plane south-eastwards to the Grampians there occurs a prominent type of crystalline schists, the Moine Series of the Geological Survey. They cover large areas in the counties of Sutherland, Ross, and Inverness, and consist for the most part of granulitic quartzose schists, which appear to have been originally of sedimentary origin. Associated with these are found masses of still older Lewesian Gneiss. From an examination of these rocks in the field it has been concluded that the Moine Schists represent a sedimentary series resting unconformably on the Lewesian Gneiss, the latter being brought to the surface by a series of inverted folds.

In the south-eastern Highlands, and occupying large parts of the counties of Aberdeen, Perth, and Argyll, constituting what we call the Grampian Mountains, we find that the Moine Schists of the north-west have been replaced by a group of metamorphic rocks, which have been termed the Dalradian Schists by Geikie. In this region there is a great series of sedimentary rocks which have been altered by metamorphism from such normal sediments as conglomerates, sandstones, shales, and limestones into schistose conglomerates, quartzite, slates, and crystalline limestones. These sedimentary rocks, prior to their metamorphism, were penetrated by intrusive igneous rocks, which have also suffered in the general metamorphism, passing into gneisses epidiorites and hornblende schists. Contemporaneous volcanic rocks have also been found associated with certain of the sedimentary groups.

All the sedimentary rocks show evidence of having been originally laid down in more or less horizontal beds or strata. They are, however, no longer seen to occupy the original horizontal position in which they were formed, but have usually been bent into a series of complex folds. These rocks have been so intensely folded that the synclines and anticlines have become closely packed together in such a way that the axes of the folds are no longer perpendicular, but are seen to be inclined in a definite direction over great areas, this being known as the isoclinal type of folding.

Digitized by Google

Two views have been advanced regarding the tectonics of these Highland rocks, but these need not be discussed here. Sufficient be it to say that the officers of the Geological Survey and the writer consider that they have been thrown into a series of anticlinoria and synclinoria in which the axes of the isoclinal folds are arranged either as pseudo-synclines or pseudo-anticlines. The other view advanced by Mr. E. B. Bailey, of the Geological Survey, is that the rocks of the Scottish Highlands are arranged in a series of recumbent folds in which the bending powers of the rocks affected have reached their limit, and the rocks have been driven forwards along slides or thrust planes. This view was originally advanced by Mr. Bailey to account for the structure of the ground south-east of Loch Linnhe, and extending from the River Spean in the north to Loch Creran in the south. More recently he has sought to show that similar structures can be traced in Argyllshire and Perthshire, still farther to the east in the Grampian Mountains. As this problem, however, does not deal directly with the question under consideration, we pass it over in the meantime. In a word we may look upon the Scottish Highlands as the basal wreck of what was in pre-Old Red Sandstone time a great mountain chain, the superstructure having been completely removed by denudation, and it is necessary before we can form a picture of the physical features of the ancient continental area upon which the later Deutozoic rocks of Scotland were accumulated that we should determine as far as the evidence will permit at what time and to what extent this denudation had taken place before the Old Red Sandstone rocks began to be accumulated.

It has been established by the Geological Survey that the Moine Schists of the north-west Highlands have been pushed along the Moine thrust plane across rocks of Cambrian age, the youngest member of which has been identified by Dr. Peach[1] as being homotaxial with the Beckmantown Chazy and Trenton Limestones of America, and he concludes that they must be older than the Arenig rocks of Wales, and probably represent the Welsh Tremadoc strata, if not part of the Lingula Flags,

[1] Presidential Address to the Geological Section of the British Ass., 1912. *Nature*, vol. xc., p. 49.

Digitized by Google

both of which, according to the English classification, are grouped with the Cambrian system.

Turning now to the rocks along the Highland border, we find that north of Stonehaven and near Aberfoyle there exist lenticular bands apparently wedged in between the crystalline schists of the Highlands and the conglomerates forming the basement beds of the Lower Old Red Sandstone. The fossils obtained from the cherty beds at Aberfoyle, according to Professor Jehu and Dr. Campbell,[2] point to them as Upper Cambrian or the passage beds into the Ordovician, the upper series or Margie Beds being placed higher up in the Ordovician. It would appear, then, that the great processes of mountain building in the Scottish Highlands had not ceased towards the close of the Cambrian and the beginning of the Ordovician period.

It is somewhat difficult to determine at what exact period the movements connected with the upheaval of the Highland mountain chain ceased. We have seen that rocks of late Cambrian and early Ordovician age have been tucked in between the crystalline schists on their north-west and south-east boundaries respectively.

We now proceed to consider the evidence bearing upon the formation of the plane of marine denudation that truncated the Caledonian mountain chain reducing it to a base level of erosion. Everywhere along the line of the great Highland boundary fault we find to the south of the fault the massive basal conglomerates of Lower Old Red Sandstone age. Lithologically these conglomerates are of two types—first, those in which boulders of quartzite or other Highland rocks predominate; and, second, those made up of fragmental materials and lavas derived from contemporaneous volcanic rocks. It is also of great significance to note that at certain localities, as, for instance, between Crieff and Comrie, and at Blairgowrie, these basal conglomerates lie on the north side of the great boundary fault, and are seen to rest with a strong unconformity upon the underlying slates and grits, and therefore presumably upon the Upper Cambrian rocks, to which reference has already been made.

Dr. R. Campbell has shown that in the neighbourhood of

[2] The Highland Border Rocks of the Aberfoyle District. *Trans. Royal Soc., Edin.*, 1917, vol. lii., p. 177.

Digitized by Google

Stonehaven there occur rocks of Upper Cambrian, Silurian, and Lower and Upper Old Red Sandstone age. The Cambrian rocks are overlaid unconformably by a series of over 2000 feet of strata, which from palæontological and lithological evidence must be looked upon as of Downtonian age. The presence near the base of this series of a set of tuffs affords evidence that the volcanic activity which culminated in Lower Old Red Sandstone time had already begun to manifest itself.

It should also be kept in mind that an outlier of Upper Old Red Sandstone rocks occurs to the north-west of Guallin Hill, near Balmaha, where it is seen to be faulted against the serpentine gabbro mass along the line of the Guallan fault. In the neighbourhood of that fault it is unconformable to the Lower Old Red Sandstone, and to the north and west it overlaps successively the metamorphic belt, the black shales, cherts, and spilites of the Lower Series—the cherts, as we have already pointed out, carrying an Upper Cambrian fauna—and the beds of the Upper or Margie Series. Finally, it is found resting on the Leny grits.

Another interesting outlier of Upper Old Red Sandstone age occurs still further to the west on the shores of Scalpsie Bay, in the Island of Bute. In this case only a small fragment rests apparently between the escarpment of the 25-foot beach and high-water mark. This hillock is locally known as the Haystack, and is about 20 yards in diameter and 25 feet high, composed of course conglomerate, consisting mainly of large angular blocks of schist and of fragments of vein-quartz. At this point the Highland boundary fault throws down the Lower Carboniferous rocks against the schists, so that the fault is in part at least later than Old Red Sandstone times.

Reference will presently be made to those outliers of Old Red Sandstone which occur at various points between the Highland boundary fault and the extreme north of Scotland. But before proceeding to these let me briefly refer to the remarkable outlier of Lower Old Red Sandstone lavas that occurs on the summit of Ben Nevis. Both in Glencoe and on the summit of Ben Nevis there occurs rocks which were undoubtedly accumulated at the surface during Lower Old Red Sandstone times. They are mainly represented by lavas and agglomerates. In

Digitized by Google

Glencoe plant remains have been identified as belonging to *Psilophyton* and *Pachytheca*. These plant remains have not as yet been found on Ben Nevis, but the lavas and fragmental rocks found on the summit of that mountain are so exactly like those seen in Glencoe that there can be no doubt as to their identity. It will be remembered that this fact was pointed out by Professor Judd in the year 1814. It seems, however, to have been generally overlooked that Professor James Nicol twenty-seven years earlier, with that marvellous prescience which enabled him to see far in advance of his contemporaries,[3] had recognised the similarity between the volcanic rocks of Lower Old Red age in the Cheviots and those of Glencoe and Ben Nevis. Under these circumstances I need not apologise for quoting his words in full. Speaking of the Cheviot lavas he says, "Compared with similar formations in our own country, they bear some resemblance to the Claystone porphyry of the Pentlands, but are in general harder and more compact. In the latter the basis of the formation approaches nearer to clay, and is more liable to decomposition than the Cheviot porphyries, which are more granular in their texture and exhibit a much higher lustre. The southern formation is also far more varied in mineral character, possessing many rocks, as the dark pitch stone, to which nothing analogous is found in the north. They have a far closer resemblance to the porphyry rocks of Glencoe and Ben Nevis, from some of which they are hardly distinguishable in mineral character. Thus some of the dark porphyries of Woodside Hill on the Beaumont are almost identical in appearance with that forming the upper part of Ben Nevis, which in some places also contains red masses similar to the veins in the porphyry of Kirk Yetholm Hill. Similar dark rocks are common in Glen Coe, where most of the brown and red varieties may also be matched, confirming the truth of MacCulloch's observation, that in that glen porphyry of every variety of colour and composition found in any other part of Scotland also occurs. Even in their conical forms the Buachaile Etive mountains resemble many of those in the Cheviots, though on a far grander scale and with a great predominance of the harsher

[3] On the Geology of Roxburghshire. "Prize Essays of the Highland Society," 1845, new series, vol. ii., p. 35.

Digitized by Google

features. The difference, however, in the two formations are not more than the rocks with which they are associated would lead us to expect, less, indeed, than between the greywacke and coal sandstones of the south and the granites, gneiss, and mica slate of the north.

It would appear, then, from the foregoing that the great processes of mountain building had not ceased towards the close of the Cambrian and the beginning of the Ordovician periods, as we find rocks of these ages involved in the north-west and south-east of the Highland mountain chain. If the Ordovician and Silurian rocks ever swept across the Scottish Highlands, no trace has now been left of their former existence. It seems not unlikely, however, that such did happen, and that during Ordovician and Silurian times the great mountain massive, of which the Scottish Highlands only form a part, was subjected to prolonged subaerial and marine denudation. The recent discoveries made along the Highland border and in the Glencoe and Ben Nevis districts all go to show that the Highlands must have been covered by a mantle of rocks the basal members of which were probably of Downtonian and Lower Old Red Sandstone age, and it is to this age that we must refer the date of the Highland plateau of marine and subaerial denudation.

That this break is a widespread one and of more than local importance has long been realised. In 1913 Dr. Olaf Holtedahl, of the University of Christiania, showed that there was a remarkable parallel between the sequence of events that took place in the early Palæozoic history of Scotland and Spitsbergen. He points out that the Spitsbergen Old Red Sandstone series rests upon the so-called Hecklahook system, the latter consisting of a thick series of crystalline sediments, phyllites, mica schists, quartzites, and limestones, which he regards as being the equivalent of the Ordovician and Silurian deposits of Scandinavia. He also points out that on Bear Island, half-way between Spitsbergen and Norway, fossils of Upper Ordovician age were found in rocks lithologically the same as those of Hecklahook. He still further points out that these crystalline sediments were invaded during the

[4] On the Old Red Sandstone Series of North-Western Spitsbergen. *Congress Geologique International*, 1913, p. 707.

Digitized by Google

processes of folding and mountain building by huge masses of intrusive granites and gneisses found in the north-western corner of West Spitsbergen. These were formerly regarded as of Archæan age. Here, again, we find a striking parallel between the Spitsbergen-Scottish formations, as it seems to us that the Hecklahook rocks might be compared with the Upper Cambrian or early Ordovician rocks seen along the Highland border. Finally, Dr. Holtedahl points out that these strong crustal movements have naturally been considered as a northern phase of the Caledonian crust movements of Scotland and the Scandinavian peninsula, and therefore were regarded as having taken place at the end of Silurian times. However, he says we have learned from our studies of the younger rocks that the chief movements probably were somewhat earlier, for we find resting on the remnants of the folded mountains a series of coarse clastic rocks containing fishes that seem to be of Silurian time. These are probably contemporaneous with the Downtonian of Great Britain and with the Red Sandstone Series of the Christiania area in Norway, where in the last few years a fauna of fishes and Eurypterids indicating rocks of younger Silurian age have been found. Before the oldest known of the Old Red Sandstone Sediments of Spitsbergen were deposited erosion worked far down into the folded range into the zones of mica schist and intrusive granite masses.

III. History of Opinion.

It is necessary that we should here give a brief summary of the various opinions that have been held regarding the physical conditions under which the Scottish Old Red Sandstone was formed. These views have been classed under two headings, namely, the marine and the continental, the latter being further subdivided into those who advocate a lacustrine origin, those who believe that they were formed under desert conditions, and those who maintain that they are of fluviatile origin. Hugh Miller,[5] Murchison,[6] and Symonds[7] advocated a marine origin

[5] Old Red Sandstone, 7th edition, p. 73.
[6] Siluria, 3rd edition, 1859, p. 270 *et. seq.*
[7] Records of the Rocks, 1872, p. 215.

Digitized by Google

for these deposits, and more recently Reid[8] and the present writer supported this view. Stratigraphically Murchison[9] divided the Old Red Sandstone rocks of Scotland into three members, the lower, the middle, and the upper, each characterised by a distinctive fauna, the lower group as seen in Scotland being principally developed along the northern and southern margins of the Midland Valley, and characterised by the presence of *Pterygotus* and *Cephalaspis;* the middle group seen in Caithness and along the borders of the Moray Firth, and containing *Dipterus*, *Osteolepis*, &c. The upper is well developed in Dura Den, Fife, and the more central parts of the Midland Valley, where they are seen to emerge from beneath the Lower Carboniferous rocks. It is characterised by *Holoptychius*, *Bothriolepis*, and other genera of fishes. Murchison also correlated the three divisions of the Scottish Old Red Sandstone lower, middle, and upper, with the similar division of the Devonian of Devon and Russia, also pointing out that in the latter country the Devonian rocks containing marine shells were also interstratified with red sandstones in which no shells were found, but which were replete with the piscine fauna common to the Scottish rocks.

Latterly, however, principally through the writings of Goodwin, Austen,[10] Ramsay,[11] and more particularly Sir A. Geikie, the Old Red Sandstone of Scotland[12] came to be looked upon as a freshwater deposit accumulated in isolated basins formed by the ridging up of the older rocks. No doubt a very attractive theory if one could simply regard the present boundaries of the Scottish Old Red Sandstone as defining the original limitation of these deposits, a view, however, which could not be entertained for one moment by any one conversant with the stratigraphical, physical and palæontological details.

[8] Palæontological considerations on the Old Red Sandstone of Scotland. *Geological Mag.*, 1896, p. 217. On the Old Red Sandstone of Scotland. *Geological Mag.*, 1896, pp. 106 and 570.

[9] *Quart. Journ. Geol. Soc.*, 1858, vol. xiv., p. 501.

[10] On the possible extension of the Coal Measures beneath the South-Eastern part of England, *Quart. Journ. Geol. Soc.*, 1885, vol. xii., p. 38.

[11] On the Red Rocks of England of older date than the Trias. *Quart. Journ. Geol. Soc.*, 1871, vol. xxvi., p. 189.

[12] On the Old Red Sandstone of Western Europe. *Trans. Royal Soc. of Edinburgh*, 1878, vol. xxviii., p. 345.

Digitized by Google

The researches of Goodwin, Austen, and Ramsay were principally directed to the petrological characters of the rocks. Sir A. Geikie was the first to isolate the Scottish areas of the Lower Old Red Sandstone into separate basins of deposit with the distinctive names of Lake Orcadie, Lake Caledonia, Lake Lorne, and Lake Cheviot. He believes that they were all contemporaneous, doing away with the existence of the Caithness rocks as a middle group, and explaining the discrepancies of their fossil contents on the ground that they are no greater than those of contiguous fresh-water basins at the present day. In the scenery of Scotland he also presents some of the physical problems connected with the Old Red Sandstone and its formation. Sir A. Geikie and his brother, the late Professor James Geikie, may be looked upon as the principal upholders of the isolated lake and freshwater origin of these deposits, and from the positions that they held in connection with the Geological Survey of Scotland their views have received a widespread acceptance by geologists of all countries.

Goodchild,[13] writing later, adopted the continental theory as to the origin of these deposits. He says there is no satisfactory reason for regarding any of the Scottish rocks of Devonian age as of marine origin, and, on the other hand, there is much to be said in support of the view that they were all formed under continental conditions and under conditions of climate which, though doubtless varying much from time to time, are yet on the whole characterised by an annual rainfall decidedly below the average in amount. It is this feature which has imparted a common character to the whole of the series of rocks. The fauna of the Upper Old Red consists almost exclusively of fishes which probably found their way into the sediments from the rivers of upland origin, whose waters were dissipated by excessive evaporation when they reached the lowland area.

As regards the mode of origin of the Old Red Sandstone of the Caledonian area (Lower Old Red) there appears to be evidence of a satisfactory nature that the whole of this vast formation was accumulated under continental conditions partly in large inland lakes, partly as torrential deposits of various

[13] The older Deutozoic Rocks of Great Britain. *Geol. Mag.*, 1904, p. 591.

Digitized by Google

kinds, partly as old desert sands, and partly as the result of extensive volcanic action.

The late Professor Barrell[14] identified himself as being closely in accord with the views just cited as held by Goodchild, except that he would give first place to true fluviatile deposition spreading sediments on broad and flat river planes a form of sediment intermediate between torrential and lacustrine, and yet quite distinct from either. He comes to the conclusion that the deposits which make up the Old Red Sandstone, although they undoubtedly contain lacustrine beds laid down in shifting, shallow, and variable bodies of water, are dominantly fluviatile in origin. The great valley in California may therefore in the present epoch, both in physiography and in climate, be cited as a striking illustration of the nature of the Old Red Sandstone basins. He also examines the evidence for the hypothesis of the continental origin of fishes, and decides in favour of it as against that of their marine origin.

IV. The Old Red Sandstone of Scotland.

Turning now to a brief consideration of the geographical distribution, physical, stratigraphical, and palæontological characteristics of the Old Red Sandstone rocks of Scotland, we find that they occur in four principal areas, namely, Caithness and the Moray Firth, Lorne, the Midland Valley, and the Cheviot Hills. In addition, there are a number of small outliers resting on the crystalline schists of the Highlands—one in Glencoe, and three in Aberdeenshire, at Tomintoul, south of Huntly, and Gamrie respectively.

We shall consider in the first place the largest of these three areas, namely, that occupying the Midland Valley, where the lower and upper divisions are best developed. Overlooking minor details the deposit of the lower division may be arranged as follows in three groups:—(1) A lower, consisting of conglomerates, sandstones, and flags, which, as we have seen, pass downwards conformably into rocks of Upper Silurian age; (2) a middle group, consisting almost entirely of lavas, tuffs, and agglomerates, as seen in the Sidlaw and Ochil Hills; and (3) an upper, consisting of conglomerates, sandstones, flags, and mudstones.

[14] Dominantly fluviatile origin under Seasonal Rainfall of the Old Red Sandstone. *Bulletin of the Geol. Soc. of America*, 1916, vol. xxvii., p. 27.

Digitized by Google

The various members of the upper group are magnificently developed along the broad valley of Strathmore from Stonehaven to the Braes of Doune, and from thence to the shores of Loch Lomond. They are seen to be arranged in a broad syncline or trough, whose axis passes approximately down the centre of Strathmore. The fossiliferous horizons in this division are confined to near the middle of the group, the Carmyllie horizon being pre-eminently the richest. Certain other horizons as Tulliewhanland Quarry, near Turin Hill, may be in the higher beds known as the Cairconnan Series. The fish fauna from the latter locality may be taken as characteristic of the series. They include the following:—*Mesacanthus mitchelli*, *Ischnacanthus gracilis*, *Climatius scutiger*, *C. uncinatus*, *C. reticulatus*, *Parexus recurvus*, *P. falcatus*, *Euthacanthus mitchelli*, *E. elegans*, *E. gracilis*, *E. curtus*, *Cephalaspis pagei*, *C asper*, and *Thelodus pagei*. The Eurypterids are represented by *Pterygotus anglicus* and *Stylonurus ensiformis*. At a lower horizon near Newtyle, but still above the volcanic rocks, occurs a led which has yielded *Cephalaspis lyelli*, *Pteraspis mitchelli* and some few acanthodians.

The lavas and ashes which form the main mass of the Ochil and Sidlaw Hills rise from beneath the syncline of younger rocks just described. The members of the lower group, consisting of massive conglomerates and sandstones, abut against the boundary fault, and, as we have seen in the neighbourhood of Stonehaven where they enter the sea, graduate down conformably into rocks of Downtonian age.

We now pass to a consideration of the development and relationship of these rocks as seen along the southern margin of the Midland Valley. In the Pentland Hills in the Esk section, and again in the Lyne Water, green shales and mudstones (Upper Ludlow) pass upwards into a conformable series of strata (Downtonian) composed of conglomerates with red sandstones and green and grey shales and greywackes. Between the Wenlock Ludlow and Downtonian strata on the one hand, and the volcanic series of the Lower Old Red Sandstone on the other, there is in the Pentlands a complete discordance, for the conglomerates, with greywacke pebbles derived from the Silurian tableland, and forming the base of the volcanic series, rest on the upturned

Digitized by Google

edges alike of Wenlock, Ludlow, and Downtonian strata. In the Upper Ward of Lanarkshire a similar strong unconformity can be seen in the neighbourhood of Tinto, where the Old Red Sandstone volcanic series of the Pentland Hills come in between Covington and Lamington and rest upon the upturned edges of the underlying Downtonian sandstones and conglomerates.

It is somewhat remarkable to find that about ten miles further to the west in the Lesmahagow Inlier no existence of an unconformity can be traced. Here the Silurian and Old Red Sandstone rocks have been folded into a dome-shaped anticline, with rocks of Wenlock age in the centre, and these pass up without a break through rocks of Ludlow and Downtonian age into the basement members of the Lower Old Red Sandstone. It has always seemed to me that the folding and unconformity seen in the Pentland Hills is in some way connected with the intense volcanic activity that existed over this area during Lower Old Red Sandstone times, and that it is of an entirely local character. Such areas must be considered in relation to the stratagraphical conditions which are known to obtain over a much wider area. But we shall return to this question presently. Reference has been made to the occurrence of lavas of Lower Old Red Sandstone age on the summit of Ben Nevis. In this district rocks of a similar age cover a large area in Lorne between Loch Melfort, Oban, and the Pass of Brander. This is Geikie's Lake Lorne; they have yielded the characteristic plant and fish remains of this division. Still another area in which these rocks are developed lies on the south side of the Southern Uplands over the east of Berwickshire and the north of Northumberland, including the area of the Cheviot Hills. This is Geikie's Lake Cheviot. It has yielded linear grass-like plants, *Zosterophyllum* and *Pterygotus anglicus*, which clearly links it with the Lower Old Red Sandstone of Forfarshire.

We now turn to a consideration of the Moray Firth and Caithness areas. The Middle Old Red Sandstone in the basin of the Moray Firth rests on a highly eroded platform of crystalline schists. At the base there occurs a course brecciated conglomerate of very irregular thickness which is overlaid by sandstones, shales, and clays. From the limestone nodules embedded in the shales numerous ichthyolite have been obtained. This

Digitized by Google

fossiliferous band, commonly known as the fish bed, forms an important horizon in the Lower Old Red Sandstone of the Moray Firth. It is exposed at Dipple and Tynet Burn. The sandstones lying above the fish bed have yielded some large specimens which are probably fragments of *Pterygotus*. The following list of the fish remains found in these rocks has been determined by Dr. Traquair:—*Diplicanthus striatis*, *D. tenuistriatus*, *Radinacanthus longispinus*, *Mesacanthus pusillus*, *Cheiracanthus murchisoni*, *C. latus*, *Pterichthys Milleri*, *P. productus*, *P. oblongus Dipterus Valenciennesii*, *Glyptolepis leptopterus*, *Gyroptychius microlepidotus*, *Osteolepis macrolepidota*, *Diplopterus agassizii*, *Coccosteus decipieus*, *Homosteus Milleri*, *Cheirolepis Trailli*. Regarding this list Traquair remarks, " As nearly all these fishes reappear in the flags of Caithness and of Orkney, it is clear that those, along with the Moray Firth beds, form one great palæontological series, the Orcadian." Supposed by Sir A. Geikie to have been deposited in the hypothetical Lake Orcadie of the Devonian period. Of this assemblage of species not one occurs in the Lower Old Red Sandstone of Forfarshire, or of any part of Great Britain south of the Grampians.

Between the Highland border and the Moray Firth there occurs two interesting and important outliers of Old Red Sandstone age, namely, at Tomintoul and Rhynie respectively. The former runs up the valley of the River Avon above Tomintoul, where it reaches a height of 1300 feet above the sea. It consists of massive beds of exceedingly coarse conglomerate, which rest unconformably in the crystalline schists. Some of the blocks measure over 6 feet in length, and have been derived from the underlying schists. At several points the conglomerates may be seen resting upon and wrapping round isolated stacks of the reddened schists and slates, indicating the very irregular nature of the surface upon which they had been deposited. Geikie contended that this outlying portion of the Old Red Sandstone was formed in a long valley connected with the main area of deposit to the north or in a separate and isolated hollow. He insists that it is not an outlier like the Ben Griam, Bheag, or Morven outliers, where mountains are capped with conglomerate, which must have had formerly a far wider

Digitized by Google

extension. This seems to us to be very specious reasoning, and that it is much more likely that the Tomintoul outlier is but a fragment of the local basement beds of the Old Red Sandstone formation that swept eastwards to Aberdeen and Stonehaven and northwards to the Moray Firth.

The other outlier is exposed about 25 miles to the east of that just described. It extends from Glaschul Hill, near Kildrummy Castle, northwards for a distance of 12 miles, coinciding with the valley of the Bogie by Auchindoir and Rhynie. This tract was first laid down upon MacCulloch's map, and fossil fish like those from Lethen on the Moray Firth were said to have been obtained from it as far back as 1839, and at a later period, 1854, obscure plant remains were found, one of which was described by Murchison as unquestionably a fragment of a large stem of a plant which measured 4 feet in length by 5 inches in width. It is nearly cylindrical, and is fluted irregularly near the pointed top. No joints or nodes are visible as in Calamites, but the surface is coarsely striated. It has been estimated that the total depth of Old Red Sandstone preserved in this district probably measures between 1500 and 2000 feet. The lowest member of the series is a bed of yellow and red conglomerate and breccia, which rests directly on the crystalline schists. This is succeeded in ascending order with some 40 or 50 feet of red shales with calcareous red nodules, above which come 300 to 400 feet of soft crumbling grey and red pebbly sandstones and conglomerates. Following these comes a group of hard pale grey and reddish or purplish sandstones, seen in the Rhynie Quarries, the whole being capped with a series of greenish grey shales and flaggy beds of sandstone. It was in the former beds that Dr. Mackie, of Elgin, discovered near the village of Rhynie a remarkable fossil peat bed preserved in bands of chert. The plants forming the peat bed grew in a gregarious fashion in peaty soil, consisting almost entirely of the decaying remains of several genera and species, which have been described by Dr. Kidston and Professor Lang. This land surface was evidently situated along the edge of some ancient shore line, and liable to periodic inundations. After the formation of the bed of peat the local conditions must have changed, for water possibly discharged from fumaroles and geysers passed over

Digitized by Google

the peat bed and sealed it up, the plants having been preserved in such a marvellous state of perfection as to be comparable with fresh sections cut from a living plant.

The Middle Old Red Sandstone of Caithness rests unconformably upon the crystalline schists and granites of the Highlands. The lower beds consist of red sandstones and conglomerates, which graduate upwards into blue and grey bituminous flagstones charged with abundant fish remains, having the same general faunal facies as that already referred to as occurring in the Moray Firth area. The late Dr. Traquair pointed out that, though the Eurypterid *Pterygotus* so typical of the Upper Silurian and Lower Old Red Sandstone rocks occurs in the Caithness flagstones, yet there are only two genera of fishes, *Cephalaspis* and *Mesacanthus*, common to the Caithness flagstones and the Old Red Sandstone south of the Grampians. It was also pointed out long ago by the late James Reid and myself that the assemblage of plants found in the Caithness beds differed in many important respects from those found in the Lower Old Red Sandstone of Strathmore. Further, Traquair pointed out that at Achanarras Quarry, south of Thurso, there occurs a peculiar fish fauna not found in any other part of Caithness. It contains, amongst others, *Palæospondylus Gunni*, *Pterichthys Milleri*, *P. productus*, *P. oblongus*, *Osteolepis microlepidotus*, and *Cheirolepis Trailli*, which had up till that time not been found anywhere else in Caithness together with *Diplopterus Agassizi*. The fish fauna from Achanarris differ from the peculiar fish fauna of John o' Groats, where the prevailing forms are *Microbrachius Dicki*, *Dipterus macropterus*, and *Tristichopterus alatus*. It also differs from the assemblage of fishes in the Thurso flagstones.

The Upper Old Red Sandstone usually consists of a series of conglomerates, sandstones, marls, and cornstones, which rest unconformably upon the upturned edges of the various members of the Lower Old Red Sandstone, and graduate upwards into the basement beds of the Carboniferous system. It is clear that the Lower Old Red Sandstone had been folded and subjected to extensive denudation before the Upper Old Red had been laid down. In the Midland Valley they usually form a fringe round the basement beds of the Carboniferous system, being

Digitized by Google

especially well developed along the north side of the Southern Uplands boundary fault. In the Midland Valley these southern deposits, as a rule, are unfossiliferous, one notable exception being the Dura Den beds in Fifeshire, where the fish remains occur in shoals. These include *Phaneropleuron Andersoni*, *Pterichthys hydrophilus*, *Glyptolæmus Kinnairdi*, *Glyptopomus minor*, *Holoptychius Andersoni*. The last form seems to have been fossilised in shoals. *Holoptychius nobilissimus* and *Pterichthys major* are found in the underlying red sandstones. Rocks of the same age have been found at the Heads of Ayr, where they have yielded *Bothriolepis major* and *Holoptychius*. North of the Grampian rocks of Upper Old Red Sandstone age fringe the coasts of the Moray and Dornoch Firths, where they have yielded the characteristic fish fauna. They also appear in Caithness at Dunnet Head, though at this locality they have not as yet yielded any fossils, in the Island of Hoy, Orkney, and in Shetland.

V. The Old Red Sandstone and Devonian of England and Wales.

Along the eastern border of Wales the highest member of the Silurian, namely, the Downtonian, passes upwards conformably into the red strata which form the base of the Lower Old Red Sandstone. Where the exact line of demarcation between the two systems is to be drawn is still a matter of dispute, and will have to be considered in the succeeding part of this address, as we consider it to have an important bearing upon the physical condition under which the Old Red Sandstone was accumulated. They have a thickness of something like 10,000 feet, and stretch from Shropshire across South Wales. Lithologically the sediments are characterised by their red colour. The lower parts consist of red and green shales and flagstones with sandstones and thin cornstones. There is no coarse conglomerate in this part of the series comparable with that of the north of England and Scotland. The middle group or Flagstone Series is of great thickness, and contains partings of red shale and irregular beds of cornstone. *Cephalaspis* and *Pteraspis* is met with in this series. The upper group consists of conglomerates and sandstones of red, purple, and green hue. The pebbles are mostly

Digitized by Google

of quartz, and vary in size from an inch or two across to small white grains. *Bothriolepis* and *Holoptychius* occur in this series.

The typical or more intensely marine conditions of the Devonian is in England confined to Devon and Cornwall, and, though it presents a striking contrast both in its lithological and palæontological characters to those of the Old Red Sandstone, it is now recognised as the geological equivalent of that system, and is capable of a similar triple subdivision into Lower Middle and Upper Devonian. They have been subdivided in Cornwall as follows:—

	Cornwall.	*Belgium and North of France.*
Upper	Entomis Shales Calcareous Slates	Famennien and Frasnian.
Middle	Torquay and Plymouth Limestones Slates and Volcanic Rocks	Eifelian.
Lower	Staddon Grits Meadfoot Beds Dartmouth Slates	Coblentzian and Taunusian.

It is pointed out by Jukes-Browne[15] that the only definite marine fossil yet found in the Dartmouth Slates is *Bellerophon trilobatus*, which is fairly common though badly preserved. It is of importance to note that three of the characteristic genera of fishes of the Lower Old Red Sandstone of Forfarshire, *Pteraspis*, *Cephalaspis*, and *Parexus*, occur in these slates. He then remarks, "hence there is no reason for regarding the Dartmouth slates as other than a truly marine deposit. At the same time, they must have been deposited in a land-locked sea or channel the waters of which were in some way rendered uncongenial to the marine life of the period. It is probable that large rivers emptied themselves into the sea and brought down so much iron in solution that few creatures except fish were able to live in the water." The frequent purple and red colouring of the slates is some confirmation of this view. The succeeding Meadfoot group consists of slates, grits, and quartzites, with their lenticular limestones containing numerous fossils, principally crinoids and brachiopods.

The Devonian rocks as they are developed in the type locality,

[15] "The Building of the British Isles," 3rd ed., 1911, p. 102.

Digitized by Google

Devonshire, are to a great extent of a normal character, and comprise grits, sandstones, slates, and limestones. These rocks enter into that part of Devon which lies north of Barnstaple and South Molton. But there also occur red sandstones, though of diminished thickness when compared with the Old Red Sandstone of Wales. These are the Foreland Grits and Pickwell Down Sandstones, both of which are coloured red, and are like those formed further north. Professor Marr remarks that the recognition of this fact induces one to believe that the contrast between the two types of rock which are found at a short distance from one another on opposite sides of the Bristol Channel is not so marked as one is sometimes led to suppose. The rocks of South Devon are characterised by more important masses of limestone as at Chudley, Newton Abbot, Torquay, and Plymouth, the beds being largely made up of corals and brachiopods. Here, again, Professor Marr remarks the apparent difference is positively greater than the real one, the limestones in North Devon having been stretched out after their formation, and thus rendered thinner. He also points out that the highly-cleaved limestones are often mistaken for shales. On the other hand, there is evidence of an apparent thickening of the limestones, really due to folding.

The fauna of the Devonian system, the phylum Cœlenterata, is represented by a vast number of corals. The Echinoderms of the period are mostly crinoids, which are abundant and widely distributed. The Annelides are numerous, one of the most common genera being Spirorbis. The Arachnidæ are principally *Eurypterids* and *Trilobites*. The former, occurring as they do in Silurian rocks, are far more abundant in those of Devonian age, and are found indifferently in sediments of the Old Red and Devon types. The trilobites belong to the genera *Phacops*, *Homalonotus*, *Prœtus*, and *Bronteus*. The *Brachiopods* are represented in great force through all the Devonian deposits. They include the older genera, such as *Orthis Strophomena*, *Lingula Athyris*, and *Rhynchonella*, as well as the newer *Spiriferidæ* and *Productidæ*. The *Lamellibranchiata* include such genera as *Pterinea* and *Megaladon*. The *Gasteropods* are represented by many interesting forms, as *Platyceras*, *Euomphalus*, and *Bellerophon*. The *Cephalapods*

Digitized by Google

are extremely abundant, and, besides the ancient types, *Orthoceras* and *Cyrtoceras*, we have now a predominance of the spirally coiled chambered shells of *Goniatites*, *Clymenia*, and *Nautilus*. The fishes include the genera, *Coccosteus*, *Phyllolepis*, *Holoptychius*.

VI. The Devonian of Central Europe.

Rocks of Devonian age have been traced across the heart of Europe from the north of France through the Ardennes, the south of Belgium, and Rhenish Prussia, Westphalia, and Nassau. A ridge of Devonian rocks stretches below the younger formations eastwards under the south of England, where its existence has been proved by well borings at London. It seems highly probable that it joins the Devonian area of the Boulonnais. The correlation of the different subdivisions of the Devonian of Belgium and the north of France with those of Cornwall is given on page 122. Fish remains occur in the Famennien, that is, the summit of the Upper Devonian. They occur at Evieux and elsewhere, and include the following genera:—*Bothriolepis*, *Cricodus*, *Holoptychius*, *Glyptolepis*, *Dendrodus*, *Phyllolepis*, and *Glyptolepis*. They have *Holoptychius giganteus* and *Dendrodus Traquairi* common to the Upper Old Red Sandstone of Scat Craig and Clashbennie, and *Holoptychius* (*Glyptolepis*), *Flemingii*, and *Glyptolepis Kinnairdi*, common to Dura Den. The higher horizon consists of sandy limestones; they contain the remains of *Dipterus*. Dr. Evans[16] states that, in a letter from M. Lohest, the fish remains consist only of the teeth and indeterminable head bones, so that we cannot be quite certain that they do not belong to *Phaneropleuron* or the Carboniferous Dipnoan *Ctenodus*. These teeth ascribed to *Dipterus* occur in the same beds with Spirifer.

VII. The Devonian of Russia.

Murchison[17] has given us a clear account of the Russian Devonian—"The lowest known Devonian strata in the north of Livonia, and thence ranging into the Government of St.

[16] "The Geology of the North-East of Caithness," 1891, p. 39.

[17] "Siluria," 2nd ed., p. 381.

Digitized by Google

Petersburg repose transgressively upon various members of the Silurian rocks. The uppermost Silurian rocks of Russia (with *Cephalaspis*) correspond to those of this country, the lowest Devonian, or Old Red stage being there absent. In Russia the lowest Devonian stage consists of the sandstones and shales which contain the fossil fishes of the north of Livonia and those of the environs of Dorpat and of Tellin on the Lake of Rustuck. The fish include *Asterolepis* and *Coccosteus*. These beds graduate upwards into limestone and shale, with mollusca of Middle and Upper Devonian types." This Murchison considered rendered the theory of the fresh-water origin of the Old Red Sandstone fish quite untenable. He further points out that where the rocks have the sandy character of the chief masses of Old Red Sandstone in the British Isles—there they are also tenanted by fishes—a remarkable geological phenomenon showing an accordance between the lithological character and organic contents of the rocks of the same age in very distant countries.

Another and not less remarkable fact obtained by the survey of these rocks as we have just stated is that fossil fishes of species well known in the Old Red Sandstone of Scotland have in several places been found to be intermixed in the same bed with those shells that characterise the system in its slaty and calcareous form as exhibited in Devonshire and many parts of the Continent. This phenomenon, first brought to light by my colleagues and myself, demonstrates more than any other the identity of deposits of this age so different in lithological aspect in Devonshire on the one hand and Central England and Scotland on the other.

The uppermost Devonian stage of Russia, whether composed of red or whitish soft sandstone or of greenish marls, as on the Priutschka River, in the Valdai Hills, contains *Holoptychius nobilissimus*, *Bothriolepis favosa*, and *Diplopterus Agazzi*. Murchison also gives a table of species common to England and Russia; of these, thirteen (including *H. nobilissimus*, *C. favosus*, *Bothriolepis major*, *Asterolepis minor*) are common to the recognised Upper Old Red Sandstone of Scotland, especially Scat Craig and other localities near Elgin.[18]

[18] *Op. cit.*, p. 382.

Digitized by Google

In Geikie's criticism of Murchison's triple division of the Devonian of the Continent, he objects to the establishment of a Middle Old Red Sandstone in Scotland with the Middle Devonian of the Continent. Amongst the reasons which he advances he says—"If one may judge from the sections in Russia and the Ural Mountains, does not attain a great thickness. It would appear to represent merely the upper part of the Old Red Sandstone of Great Britain. The occurrence in it of a few other types of fishes like those just cited cannot be regarded as evidence sufficient to establish a 'Middle' Old Red Sandstone series in Britain. It may merely show that in the basin of the east of Europe certain species of fishes survived longer than any seem to have done in Lake Orcadie."[19]

VIII. The Old Red Sandstone of Spitsbergen.

Reference has already been made to Professor Holtedahl's work on the Old Red Sandstone of north-western Spitsbergen. He has recognised the following divisions and their correlation with the Scottish Old Red Sandstone:—

In Spitsbergen.	*In Scotland.*
Wijde Bay Series (Upper Devonic).	Upper Old Red.
Grey Hoek Series (age unknown).	Middle Old Red (Orcadian).
Wood Bay Series (Lower Devonic).	Lower Old Red (Caledonian).
Red Bay Series (Highest Siluric).	Downtonic.

The Red Bay series rest upon the more or less crystalline sediments of the Heclahook system, which consist of phyllites, mica schists, quartzites, and limestone, and which are regarded as equivalent to the Ordovician and Silurian system of Scandinavia. The Red Bay series constitute the basal member of the overlying clastic series. Resting directly on the Heclahook schists are massive conglomerates. The contact between the Heclahook system is usually marked by huge sharp-edged pieces of loose rock that have not been moved at all, but represent the fractured older formation. Higher up the conglomerate materials become smaller, more rounded, and exclusively quartzose. The thickness of the conglomerate is 500 to 600 m., in some places probably more. These basal beds are followed by a yellowish white, coarse, moderately cross-bedded

[19] "Old Red Sandstone of Western Europe," p. 366.

Digitized by Google

and unfossiliferous sandstone 100 to 200 m. thick. These are succeeded by the oldest known fossiliferous beds of Spitsbergen, which consist of a great thickness, grey green, and in some layers reddish sandstone. In certain layers there occurs a rich and well-preserved fauna, consisting of placoderm fishes belonging to the genera *Pteraspsis*, *Palœaspis*, *Cephalaspis*, and some new genera. On two horizons are found badly preserved ostracods, *Leperditia* or *Isochilina*, and in addition some species of lamellibranchs. According to Professor Kiär, of the University of Christiania, these fishes probably represent highest Siluric time.

The succeeding division, namely, the wood Bay series, have been correlated with our Lower Old Red Sandstone (Caledonian). They consist of red and chocolate coloured sandstone and shales. They have yielded the following genera of fishes:—*Pteraspis*, *Cephalaspis*, and *Acanthaspis*. Beside the fishes ostracods and plant remains have been found; the ostracods are a big *Leperditia* and an *Isochilina*.

The next division in ascending order is the Grey Hoek series. The age of this series is not definitely known, but they have been provisionally placed as Middle Old Red (Orcadian). The fauna consists of a vast number of individuals belonging to but a few species of lamellibranchs and a gastropod. The lamellibranchs include the genera *Aviculæ*, *Myalina*, *Palœonodonta*. No other fossils, except some fish and plant remains, have been found.

The Grey Hoek series is overlain without any marked unconformity by the uppermost known Devonian group, namely, the Wijde Bay series. They consist of grey sandstones and slates, with the Upper Devonian fishes belonging to the genera *Holoptychius* and *Psammosteus*. Professor Holtedahl points out that the Downtonic-Devonic beds of Spitsbergen have an enormous thickness, amounting to about 10,000 m. We have here, in fact, he says, a very interesting parallel to the famous Scottish Old Red system.

As regards the physical conditions under which these rocks were deposited, the professor makes the following remarks:—"A point of difference between the two areas is that in Spitsbergen conditions from Lower to Upper Devonic time were

Digitized by Google

more stable with a less interrupted deposition in one great basin, while in Scotland great tectonic disturbances took place during this period, causing a strong denudation and the formation of more isolated troughs of deposition. Another and very interesting difference is indicated by the occurrence of fossils of distinctly marine type, such as some of the lamellibranchs and big ostracods in the Spitsbergen series. It looks as if the Spitsbergen basin was at no time during the periods of deposition far beyond the reach of the sea. We probably shall come nearest the truth by imagining a widespread delta deposition, with partly fresh partly brackish water that periodically covered great areas of the flat delta land. The Grey Hoek series, with its homogeneous shale deposits and its small fauna of lamellibranchs, was probably laid down in a large lagoon-like body of water, in which the scanty fish remains were carried down by rivers.

"That we know from investigation both in Great Britain and in the Scandinavian countries that in general in Ordovician and Silurian times a land of great extent lay to the north-west, that is, on the Atlantic side. In Scotland and the north of England we find immense masses of coarse clastic material coming from this land, and in Norway the Silurian limestones of the Christiania area are replaced to the north-west by clastic material that was derived from the west. We are able to see how the western upheaval gradually spread towards the south-east accompanied by a deposition of red sandstones along the south-eastern border. In the north-south belt of unmetamorphosed sediments in south-eastern Norway—the Christiania area—we observe that the marine deposition is replaced to the north by the barren sandstone in late Wenlock time, while to the south a similar change first appears at the beginning of Downtonian time, where the marine beds are followed by fish bearing red sandstone."

IX. The Devonian of North America.

The Devonian system is extensively developed in North America, its conditions and successions being persistent over large regions. The State of New York and the Canadas, with the Gaspé region in the east, exhibit the different members of

Digitized by Google

the system in its fullest development. The Hamilton and Upper Helderberg groups, with the Catiskill, Cheamung, and Portage groups above, occur in the States of Pennsylvania, Ohio, Illinois, Missouri, and Michigan in full development. In Iowa and Tennessee the Upper Devonian only is present. In New York State the eleven recognised divisions make up a mass of limestones, sandstones, shales, flagstones, and conglomerates upwards of 8000 feet in thickness. In Pennsylvania the Devonian rocks are 12,000 feet thick.

On the Lower Devonian series traces of terrestrial plants, *Psilophyton*, *Caulopteris*, &c., have been detected as far west as Ohio. This division has also yielded corals of a cyathophylloid type, *Favosites*, *Syringopora*, &c. The brachiopods include the genera, *Pentamerus*, *Stricklandia*, *Rhynchonella*, *Spirifer cultrijugata*, a European form, and *Atrypa reticularis*, which has a world-wide distribution. Trilobites, belonging to the genera *Dalmanites*, *Proëtus*, and *Phacops*, are present. Fishes are represented by ichthydorulites and teeth of Cestraciont and hybodont placoids, with plates, bones, and teeth of some peculiar ganoids, *Macropeta-lichthys* and *Onychodus*.

The Portage and Chemung groups contain land plants and fucoids, some crinoids, numerous broad-winged Spirifers, with Aviculæ and a few other lamellibranchs, as well as the characteristic Upper Old Red Sandstone genera of fishes, *Holoptychius* and *Bothriolepis*. Succeeding the Chemung there comes an immense thickness of red sandstones and conglomerates which bear a striking resemblance to the Old Red Sandstone deposits of Scotland. They are known as the Catskill group. Professor J. J. Stevenson[20] states that the study of the fauna of these three divisions of the Upper Devonian rocks of the Appalachian Basin shows us that as far as any evidence exists the conditions were marine from the beginning of the Chemung period to the close of the Catskill, that in the early Chemung, or possibly in the Hamilton, the conditions within north-east Pennsylvania and the adjacent portions of New York, became unfavourable to the free development of animal life, and that

[20] Address before Section of Geology and Geography, American Ass. for the Advancement of Science. *Proceedings*, vol. xl, 1891.

Digitized by Google

as time went on these conditions were gradually extended southward and westward, so that towards the close of the Chemung they prevailed in Columbia County 50 miles south-east from the Delaware River, and in Bradford County about the same distance west from the outcrop line. Before the close of the Catskill they had reached southwards beyond James River, in Virginia, but had not extended much further west in Pennsylvania and New York. But while prevented from existing in the muddy shallows the animals existed further west in the basin beyond reach of the river silts, just as soon as an opportunity was afforded by a lull in the untoward conditions. The active fishes found their way eastwards again, to be followed if the interval were long enough by the more sluggish molluscs as in New York and in Roanake and Russell Counties of Virginia.

The following is Professor Stevenson's summary of his paper:—

First, that the Chemung and Catskill deposits were laid down in a shallow basin subsiding most rapidly at the east and along a line roughly parallel to the Blue Ridge trend.

Secondly, that the deposits would be much greater near the mainland than at 200 miles away; so that 600 feet more or less of fine material in Ohio would more than fairly represent the 4000 feet of Chemung in eastern Pennsylvania: and

Thirdly, that the water beyond the reach of the great land wash held a Chemung fauna throughout the whole time of the Catskill deposit. There will be no serious difficulty in the way of accepting these suggestions.

The conclusions to which I am led are—

First, that the series from the beginning of the Portage to the end of the Catskill forms but one period, the Chemung, which should be divided into three epochs, the Portage, the Chemung, and the Catskill.

Secondly, that the deposits of the Catskill epoch were not made in a closed sea or in fresh-water lakes.

Thirdly, that the disappearance of animal life over so great a part of the area towards the close of the period was due to gradual extension of the conditions in south-eastern New York as early perhaps as the Hamilton period.

Digitized by Google

Fourthly, that the Chemung period should be retained in the Devonian.

Professor Stevenson insists that wherever the fishes of this period are associated with any other form of animal life, that form is marine, so that the ordinary presumption should be that the fishes themselves are marine.

Devonian rocks are widely distributed over Canada. The earlier beds are often largely calcareous, and their fossils indicate true marine conditions, but with these are associated shales and sandstones rich in the remains of land plants, and at once reminding us of the Scottish Old Red Sandstone type. These no doubt represent contemporaneous estuarine or lagoon conditions. In Nova Scotia and New Brunswick the so-called Knoydart Formation of red shales and sandstones and calcareous bands apparently overlies the Silurian (Arisaig series) unconformably, and a volcanic ash bed in the series contains pteraspidian and ostracoderm fish (*Cephalaspis*, *Pteraspis*), and eurypterids (*Pterygotus*). It resembles the cornstones of the Lower Old Red Sandstone of Great Britain. At Scaumenac Bay, Chaleur Bay, in Quebec, these fish-bearing sandstones and shales seem to lie above marine deposits, containing a lower middle Devonian fauna.

X. Consideration of the Stratigraphical and Physical Evidence.

We now proceed to discuss the bearing of the stratigraphical and physical evidence upon the conditions under which these rocks have been accumulated, and it will be necessary for us to institute a comparison between the Scottish areas and others in the British Islands as well as point out the bearing which the Devonian rocks of the Continent and other parts of the world have upon the problem. The question of the contemporaneity of the Caithness and Moray Firth Beds with those of the Midland Valley and of the existence of the Cheviot, Lorne, Caledonian, and Orcadian areas as separate fresh-water lake basins, though still upheld by Sir A. Geikie, need not be here discussed, as this view has been generally abandoned by Scottish geologists. In Fig. 1 we have given Jukes Browne's idea of the geography of the Lower Devonian period. It will be seen

Digitized by Google

that he here adopts Geikie's contemporaneous fresh-water lakes. This restoration of the palæography of the British Isles during Lower Devonian times was given by Jukes Browne in the first and second editions of the "Building of the British Isles."

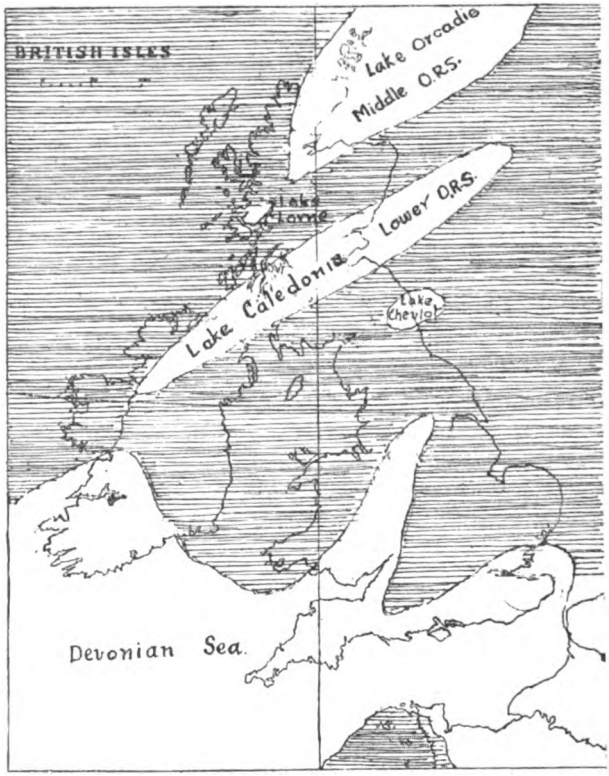


Fig. 1.—Geography of the British Isles in Devonian Time.
After Jukes Browne, 1886.
This map is based on Sir A. Geikie's Theory.

In a later edition of the same work the author resiles from his former position, and, whilst still retaining the Lake Monmouth of South Wales, he sweeps the whole of the Scottish areas into one great basin, which includes Lake Orcadie, Lake Caledonian, Lake Lorne, and Lake Cheviot. He still looks upon Lake Monmouth as a separate lake basin; his reasons for sweeping Geikie's separate Scottish basins into one are given as follows:—

Digitized by Google

It must be admitted that the occurrence of Lower Old Red in Lorne makes it very probable that difference of level was not sufficient to exclude that series entirely from the Orcadian area. Hence the most reasonable view when all the facts are taken into consideration is that all the areas of deposition eventually communicated with one another, but that it was only during the later part of the Caledonian stage that deposition began in the Orcadian area. There may have been at that time some differential sinking in of the interment tracts increasing the relative depth of the Orcadian basin, and at the same time it seems to have become stocked with fish which could not have reached it by any southern route. With regard to Lake Caledonia, he further states that he sees no reason for imagining that the Lorne and Cheviot areas were not parts of it. He admits that Messrs. Macnair and Reid were certainly on the right track when they pointed out that some of the fish genera found in the Caithness flagstones occur also in the Middle Devonian of Russia and North America, and he points out that since they wrote Dr. Traquair has shown that the fish fauna of Caithness is undoubtedly newer than that of Forfar, and much nearer in its general affinities to that of the Upper Old Red. This view has also been supported by the authority of Dr. Smith Woodward. On the other hand, Jukes Browne points out that Macnair and Reid were disposed to regard the whole succession of deposits from the Downtonian of Lanark to the top of the Caithness Beds as a marine series formed on successive platforms during the subsidence of the whole region beneath the sea. This theory, he further says, ignores some important facts and creates as many difficulties as it explains. Map II. gives his more recent view as to the geography of the Lower Devonian period. It will be seen that whilst putting Geikie's separate Scottish basins into one he still retains the Anglo-Welsh area as a separate fresh-water basin. It seems to me that nothing could exceed the specious character of the whole of Jukes Browne's reasoning on the palæography of the British Isles during Devonian times as set forth in the third edition of the "Building of the British Isles." The following may be taken as an example. In attempting to explain the middle or Orcadian Old Red and its relation to the Lower or Caledonian

Digitized by Google

Old Red on the supposition that they were both deposited in the same lake basin, and also the divergence of the fish fauna, Jukes Browne says that in Middle Devonian time there was

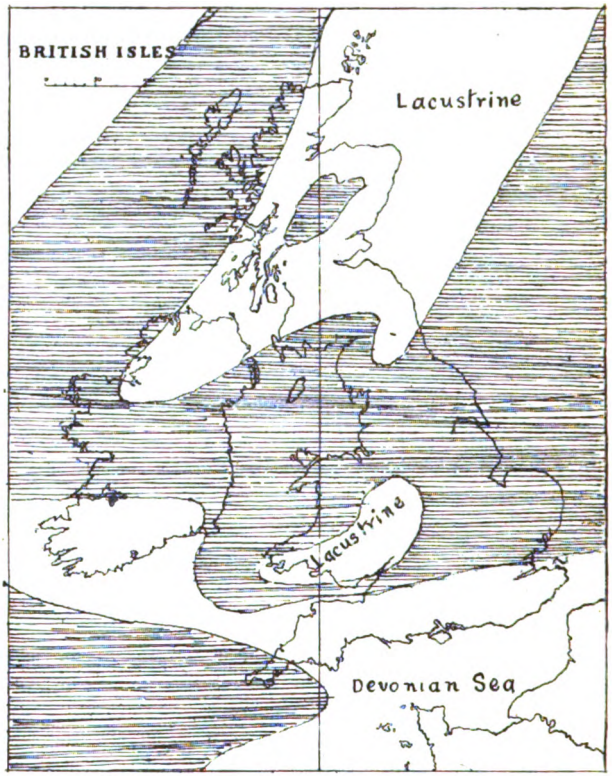


Fig. 2.—Geography of the British Isles in Devonian Time. After Jukes Browne, 1911.

an unequal tilting movement of the Continental region, its south-west portion (Ireland and Wales) being raised, while its northern and eastern parts were depressed. This would lead to some alterations in the drainage system, and, whereas the outlet of the Caledonian lake had previously been a river flowing across the centre of Ireland into the southern sea, the subsidence in the north-east may have caused an outlet to be

Digitized by Google

established from the Orcadian basin into the Polar Sea, and by this outlet the fish of the Middle Devonian Seas would obtain access to the Orcadian basin.

It is necessary that we should here consider in some detail the nature of the palæontological characteristics of the passage beds between the Silurian and the Old Red Sandstone of the Midland Valley and compare them with those of England and the Continent. In the Lesmahagow district, as we have already seen, there appears to be a conformable upward succession from the Wenlock of the Upper Silurian to the Lower Old Red Sandstone. The lowest well-defined fossiliferous horizon is that seen in the Logan Water above Logan House, which has yielded the following species:—*Archidesmus loganensis*, *Ceratiocaris longa*, *C. Murchisoni*, *C. papilio*, *C. stygus*, *Slimonia acuminata*, *Pterygotus bilobus*, *Physocaris sp.*, *Lingula minima*, *L. Lewisi*, *Pterinea retroflexa*, *Platyschisma* (*Trochus*) *helicites*, and the fishes *Thelodus planus* and *T. scoticus*. These are regarded to be of Ludlow age, and the beds are clearly of marine origin, and the genus *Thelodus* must be considered as a marine fish. It is interesting to note here that *Thelodus* occurs in the Downtonian fish bed. In the Hagshaw Hills the Ludlow rocks have yielded such brachiopods as *Orthis*, *Strophomena*, *Rhychonella*, and *Glassia*, and, as we have seen, they are accompanied on this horizon by a molluscan fauna in which species of *Pterinea*, *Modiolopsis*, and *Orthoceras* are the most abundant types. The description of the transition from the Upper Silurian rocks into the Lower Old Red Sandstone of Shropshire, as given by Dr. H. L. Hawkins, might equally apply to those of the Lesmahagow inlier.

After describing a similar Ludlow fauna to that found at Lesmahagow, he says, "As the flags pass up towards the Downtonian Sandstones the proportions of the groups undergo reversal. Almost the only brachiopods are *Lingula*, *Orthoceras* disappears, and the bulk of the fauna is composed of *Pelecypods*, with occasional tubiculous annelides and Eurypterid Arthropods. The Ludlow Bone bed gives striking testimony to almost catastrophic changes at this stage, and in the Downtonian that supervenes even Pelecypods have gone. *Lingula* alone survives, represented by dwarfed forms, such as *L. minima*. The

Digitized by Google

micaceous strata of the passage beds enclose *L. cornea*, and then almost all palæontological evidence is lost in the marls of Lake Monmouth. The gradual transition from marine through brackish to fresh-water conditions is very clearly shown in the faunal sequence. The higher brachiopods are exclusively marine, and disappear at the first suspicion of estuarine contamination. Many Pelecypods (especially the Mytilidæ, a group nearly related to *Modiolopsis*) are indifferent to dilution of sea-water, although they cannot survive when sweetness has been quite attained. The Cephalopods are as definitely marine as the Brachiopods, but *Lingula*, one of the simplest members of the latter phylum, may well have possessed the catholicity of taste common to the most lowly forms."[19]

Dr. Lawrence Dudley Stamp,[20] who has recently reviewed the question as to the proper base of the Devonian, more especially in the Welsh borderland, urges a return to Murchison's original base line, namely, the Ludlow Bone Bed, as being the most natural line of delimitation. It consists of fish remains, all of which just appear on this horizon, and are genetically connected with higher Devonian faunas. It passes laterally into a conglomerate, and thus forms a natural physical base; it marks a palæontological and lithological break, which can be correlated all over north-western Europe. Dr. Stamp says a study of the palæontology of the Downtonian of the Welsh borderland shows that the fauna of the lower beds (Ludlow Bone bed, Downton Castle Sandstone, and *Platyschisma* Shales) falls into three groups—

(*a*) Upper Ludlovian marine species, which survived the change of conditions indicated by the bone bed and lived on in diminished numbers, but gradually die out. The *Platyschisma* Shales of Clun Forest are of deeper-water type than the Downton Castle Sandstone, and still other marine forms occur.

(*b*) Species which flourished for a short time under the changing conditions.

[19] "Invertebrate Palæontology," 1920, p. 85.

[20] On the Determination of the Limit between the Silurian Devonian Systems. *Geol. Mag.*, vol. lvii., p. 164, 1920. The Base of the Devonian with especial reference to the Welsh Borderland. *Proceedings Geol. Soc.*, No. 1075, 1921.

Digitized by Google

(*c*) New forms—chiefly fishes—which persist or are closely connected with later Devonian forms.

In the Lesmahagow inlier the Downtonian fish bed, lying immediately below the quartzite conglomerate, carries a fauna of ostracods, phyllocarid crustaceans, eurypterids, and fishes. One of the most striking features of this horizon is the remarkable assemblage of fishes in a wonderful complete state of preservation which it has yielded. Amongst them is the genus *Thelodus*, which we have seen occurs in the underlying Ludlow Bone Bed and in the Lower Old Red Sandstone of Forfarshire and Oban. The general aspect of the faunal association of the Downtonian fish bed at once recalls that of the lower or Ludlow horizon, both of which are of a clearly marine type, as pointed out by Drs. Peach and Horne. Now, if *Thelodus* is marine in the Ludlow and Downtonian, how does it come to be freshwater in the Lower Old Red Sandstone? Further, the occurrence of the Polyzoon *Glauconome*, together with *Spirorbis* and sponges, also indicate a marine origin for the Lesmahagow Downtonian. In connection with this matter Dr. Stamp suggests that from the association of the early Devonian fishes with marine invertebrates that they could live in either salt or brackish water, but gradually became specialised—some for a lacustrine habitat, others perhaps for marine conditions.

It seems to us that when we consider the widespread area over which these physical conditions prevailed, namely, Scotland, Wales, Devon and Cornwall, Northern France, the Ardennes, Brittany, Portugal, the Baltic lands, Spitsbergen, and North America, that it entirely precludes the possibility of there having been any great terrestrial earth movements such as could have ridged up the Silurian sea floor into basins as required by Sir A. Geikie's theory. Further, the gradual transition from the Downtonian to the Lower Old Red Sandstone type of deposition over such a large region of the earth's surface is only explicable on the assumption that the whole region involved shows the transition from a widespread Downtonian sea to more localised littoral conditions.

In the Silurian of the Lesmahagow inlier the marine Ludlow is succeeded conformably by a band of local conglomerate which in turn passes upwards into a series of red and yellow false

Digitized by Google

bedded sandstones having a thickness of 1300 feet, and which are entirely destitute of fossils. These are succeeded by 100 feet of green and red mudstones in which occurs the Downtonian fish band, with its overlying quartzite conglomerate. This is followed by 1200 feet of chocolate-coloured sandstones, also destitute of fossils, which have been placed by the Survey in the Downtonian. According to the Survey view, then, the Downtonian strata range from the strata above the Upper Ludlow to the Cephalaspis Lyelli beds of the Lower Old Red Sandstone.[20a]

The occurrence of the marine Downtonian between the underlying yellow sandstones and the overlying chocolate-coloured sandstones points to the fact that sea could not have been at any great distance away, and the fact that the Downtonian fish bed conformably intercalated between the sandstones precludes any great ridging up movement into isolated basins.

Turning now to the lithological aspect of the question, we find that there is a strong similarity between the conglomerates of the Torridon sandstones and those of the later Old Red Sandstone rocks, and it has been claimed that both of them show evidence of glaciation. It seems to us that this may be connected in some way with the fact that they both seem to follow a great process of mountain building. This fact we think would indicate that the great mountain mass had been upheaved above the limit of the snow line, the consequent descent of glaciers having played an important part in contributing their morainic débris to the formation of these massive conglomerates now lying at the base of both the Pre-Cambrian and the Old Red Sandstone deposits, the origin of which is not, we believe, to be sought for in any lacustrine deposits as has been maintained by Ramsay, Geikie, and others. They are rather types of a great series of shore deposits gradually accumulating along the margin of a slowly sinking continental area which in its upper regions is rapidly undergoing subaerial denudation.

[20a] So far as I am aware the only locality at which *Cephalaspis Lyelli* has been found in the Lesmahagow inlier is in the rocks of the Nethan Water at Lesmahagow, where some years ago Mr. Wm. Clarkson found a head shield of that fish. According to the officers of the Survey this is on the same horizon as those exposed in the River Clyde for a few miles both above and below Lanark. See *Memoirs of the Geol. Survey Explanation of Sheet* 23, p. 13.

Digitized by Google

This type of deposit is not uncommon all through the geological scale, and to it we believe the Old Red Sandstone conglomerates of Scotland belong. The whole petrological aspect of the Old Red Sandstone rocks as seen in Scotland is, of course, highly indicative of littoral origin, the entire absence of any of the deeper oceanic types of sedimentation, such as limestones, also confirming this view.

The great feature of the Scottish Old Red Sandstone rocks is their characteristic red colour. Now, we think that this red colour, due to the presence of the red oxide of iron in the rocks, cannot be fairly claimed as an argument for the fresh-water origin of these deposits. Professor Gosselet[21] has shown that in the Devonian basin of Dinant the same beds are in one part red and barren of organic remains and in another part of the same area are of the usual colour and full of marine fossils. In the area he recognises two bands—a northern and a southern—and sums up his conclusions as follows:—

What distinguishes above all the two bands is—

(1) The presence in the northern band of red schists intercalated throughout the series, whilst in the southern band the red colour is concentrated towards the base and the upper part.

(2) The absence of fossils in the same band. This second fact is perhaps a consequence of the first, for fossils are lacking also in the red shales of the southern band.

(3) The grit rock of Montigny is lacking in the northern band, or else is replaced by the gres de Wepion, where one finds the débris of *Sagenaria*.

To the east of Liège the southern band forms an arch which is several times folded, and where are found only the superior beds—puddingstone and red schists. At Pepinsterre it bifurcates, one branch passes towards Eup and is bounded on the north by the Silurian massive of Stavelot, whilst another branch passing towards the south unites with the southern band.

On the eastern edge of the basin of Dinant the Lower Devonian stage approaches the northern band by the numerous

[21] Etudes relatives au Bassin Houiller du Nord de la France. *Bull. Soc. Geol.*, France, T1, p. 409.

Digitized by Google

red rocks with which it is intercalated and by the absence of the greywacke of Hièrges. Following step by step the beds towards the south one sees them passing gradually from the northern to the southern facies.

Thus from the beginning and all through the Devonian period the Dinant basin was an arm of the sea wherein the deposits were laid down without any lacuna or breaks. I insist in this latter fact because that in all admitted theories up to the present time the Rhenan Terrain was lacking on the northern edge, whilst the puddingstone of Burnot was very much reduced upon the southern edge.

Some English geologists suppose that the Old Red Sandstone was deposited in lakes. They come to this conclusion from the absence of marine fossils, from the nature of the fishes, and from the red colour of the beds.

The first argument has no weight, as one does not find in them any fresh-water shells. As for the ganoids there, modern representations of which are very few, live, it is true, in fresh water, but if one concludes from this that the primitive ganoids had also the same habitat it must be admitted that in those distant ages all fishes belong to the fresh water, with the exception of a few plagiostomes, the remains of which are found along with marine shells of carboniferous age.[22]

At the same time I do not intend to deny that the Old Red Sandstone of the British Isles cannot have had a continental origin; what I wish to protest against is the idea that the red colour is a proof of this origin. In the basin of Dinant the beds of the northern band only differ by their red colour from the beds of the southern band which have the more manifest marine characteristics. One can pass horizontally from the one to the other and show that there existed no separation between the two parts of the basin.

According to Ramsay, the red colour is due to each grain of sand or sediment being covered by a thin coating of sesquioxide of iron, and he supposes that from the protoxide of iron held in solution in the waters of the lake it was deposited under the form of peroxide owing to the oxidising action of the air and to the liberation of the carbonic acid which held it in solution.

[22] "Geol. Record," 1876, p. 329.

Digitized by Google

I admit this theory, but I think that this reaction has been *perfectly* able to take place in the sea under the influence of a current which carried along the edge of the water feruginous matter from its source or from tributary streams. These mineral waters were inimical to life, and wherever the current was flowing the mollusca fled towards a more hospitable part of the beach. It is because of this that these red rocks are to-day devoid of fossils.

With Sir Charles Lyell[23] we ask the question, why should shells and corals be generally wanting in all sedimentary rocks the colour of which is determined by the red oxide of iron? And we believe that the answer cannot be in the assertion that they are all fresh-water deposits, seeing that even in such undoubted marine deposits as the Devonian, Carboniferous and Permian formations it is common in the ordinary beds to find corals and shells, whilst those coloured with peroxide of iron are entirely barren of organic remains. The solution of the problem rather lies in the fact that the presence of peroxide of iron in these rocks is inimical to the preservation of fossils with a calcareous test, and more especially so the case of sandstones, which even when composed of pure silica are well known to be a bad medium for the preservation of molluscan and other similar organic remains.

We need not stop to discuss here the analogy we propose to draw between the two types of sedimentation found in the Devonian and the two types found in the Carboniferous. That will be fully discussed in the next year's address when we pass to a consideration of the physical conditions under which the Carboniferous rocks were deposited. We may simply indicate, however, the general nature of the argument. In the Lower and Upper Carboniferous Limestone Series of the Glasgow district there is often found interbedded with true marine limestones and shales thick masses of sandstone devoid of organic remains of any kind. Now, this entire absence of fossils has led many of the local geologists to the conclusion that such sandstones as the Giffnock Sandstones and the Barrhead grits and sandstones must have been accumulated in fresh water. The fact that they are intercalated with marine limestones and shales

[23] "Elements of Geology," 3rd ed., p. 435.

Digitized by Google

is sufficient presumption of their marine origin. It is hardly conceivable that each alternation of such strata represents a withdrawal of the sea and a return to fresh-water conditions. This line of argument was first stated by me in my paper on the Physical Geology and Palæontology of the Giffnock Sandstones and their Bearings on the origin of sandstone rock generally, which may be consulted for further details.[24]

XI. Palæontological Considerations.

In a paper published in the *Geological Magazine* for 1896 by the late James Reid and myself, we sought to show that however paradoxical it may appear to be, we have reason to believe that the occurrence of so-called ganoidan fishes of a fresh-water type in the Old Red Sandstone affords the strongest evidence of its marine origin. That recent representatives of the ganoids and dipnoans of the Old Red Sandstone inhabit rivers and lakes of the globe is by no means a proof of the fresh-water origin of these fishes. The immense interval of time implied by the comparison renders its value somewhat problematical. Sir A. Geikie, in referring to the fishes of the Old Red Sandstone, says "That some of the fishes found their way to the sea as our modern salmon does is indicated by the occasional occurrence of their remains among those of the truly marine fauna of the Devonian rocks."[25]

The life history, however, of the salmon presents evidence of a somewhat different kind, for we find that the salmonidæ made their appearance for the first time in the chalk of the Cretaceous System, which would rather indicate a migration from the sea. In like manner the life history of these obscure representatives of the ganoids of the Old Red Sandstone would probably show that they preserved their existence in the struggle for life by a successful adaptation to new surroundings, namely, fresh-water conditions, while their less favoured contemporaries succumbed.

We have seen that the late Professor Barrell regarded the Old Red Sandstone as of fluviatile origin; as regards the fauna he says—"At the opening of the Devonian the acanthodian

[24] *Trans. Geol. Soc.*, Glasgow, vol. xi., p. 199, 1897.

[25] Palæontological considerations on the Old Red Sandstone of Scotland. *Geol. Mag. Decade IV.*, vol. iii., p. 217, 1896.

Digitized by Google

sharks were the dominant fishes in the continental waters. Dipnoans and crossopterygians were not in evidence in the regions where the fossils have been preserved. In the Upper Devonian the sharks were gone from the fresh waters, but the

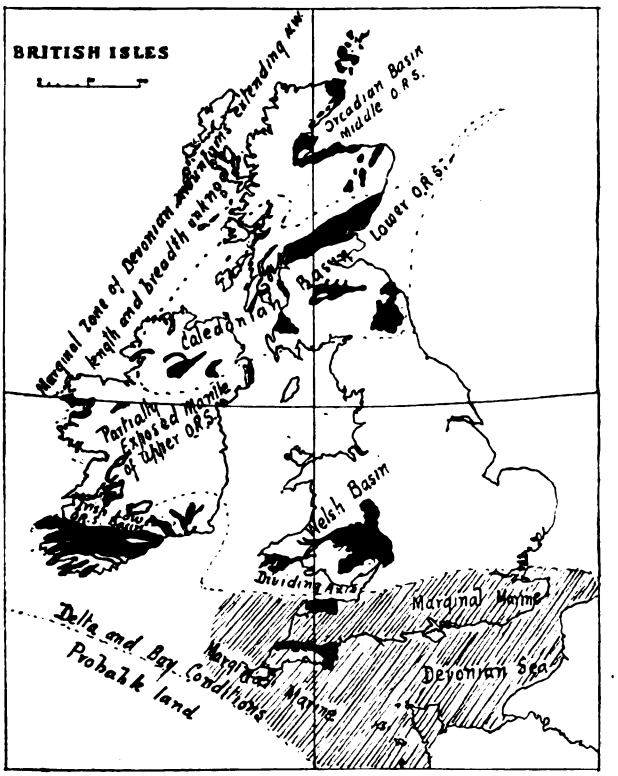


Fig. 3.—Geography of the British Isles in Devonian Time. After Barrell, 1915.

The loci of deposition of the Old Red Sandstone of the Lower and Middle divisions are shown and interpreted as river basins not as lakes, though subordinate lacustrine phases would attend fluviatile deposition. The outcrops of Devonian formations are shown in black.

crossopterygians had risen in that environment to a dominant place. Their ability to utilise air adapted them better as river fishes to warm climates marked by alternation of wet and dry seasons. It was a semi-arid rather than an arid or humid climate which characterised the regions of the Old

Digitized by Google

Red Sandstone during late and most of Devonian time. The climate of much of the torrid zone at the present time may give the best illustration of the conditions of temperature and rainfall which in the Silurian and Devonian, but especially in the later Devonian, characterised the northern hemisphere. The few remaining dipnoans and crossopterygians still live as fresh-water fishes under similar climatic conditions.

With regard to the introduction and geographical distribution of the fishes of the Old Red Sandstone, the case of the lake or fluviatile theory displays conspicuous weakness. The Eurypterids and the Cephalaspidians of the Upper Silurian are in evidence, but of the genera *Osteolepis*, *Dipterus*, *Glyptolepis*, and other fishes of the Old Red Sandstone, no undoubted plates or scales occur in the preceding formation. The question therefore arises, whence came these highly organised fishes of the Old Red Sandstone? More especially, from what fresh-water region did they migrate? Not only so, but as the same genera of fishes occur in the Devonian of North America and the St. Lawrence basin, we have an equal right to know by what fresh-water pathway of distribution they were enabled to migrate some 3000 miles between one point and another.

We find Sir A. Geikie stating that no unequivocally marine fossil remains occur in the Old Red Sandstone. We believe we are correct in assuming that our author refers to the fishes and arachnids alike as equivocally marine remains. We have, however, seen no reason assigned why Eurypterids and Placoderms of the same genera which are marine in the later Upper Silurian and fishes of the same genera and species which are equally marine in the Devonian of Russia and Central Europe, as well as in the Devonian of North America, should be termed equivocally marine in the Old Red Sandstone.[26]

The occurrence of *Anodonta Jukesii* in the Old Red Sandstone of Ireland is often cited as favourable to the fresh-water theory of its origin. It is being regarded as a fresh-water shell; but there is no positive proof of this, for though *A. Jukesii* may have been the ancestor of the modern fresh-

[26] "Text-book of Geology," 1882, p. 706.

Digitized by Google

water *Anodon*, yet its own ancestors were probably marine molluscs, and the theory of its fresh-water habitat is much weakened by its occurrence in the Tuedian beds of Northumberland, which also contain stunted marine shells. It may have preferred brackish water to fresh, or was capable of living in either. It is also interesting to note that a large lamellibranch closely resembling the Irish Anodonta is met with in the Devonian of New York.

From all the evidence that has been adduced, we feel justified, upon both physical and palæontological grounds, in concluding that the Old Red Sandstone and Devonian in their respective littoral, shallow-water, and deep-sea deposits, represent the one Devonian system which is marine.

Digitized by Google

PROCEEDINGS OF THE GEOLOGICAL SOCIETY OF GLASGOW.

SESSION 1919-1922.

(Sixty-second to Sixty-fourth Sessions).

Society's Rooms, 207 Bath Street, 9th October, 1919.

The first meeting of the sixty-second Session was held here this evening—Mr. G. W. Tyrrell, *Vice-President*, in the chair.

Mr. Archibald Hood, M.A., proposed by Mr. D. B. Duncanson and seconded by Mr. James Begg, was elected a member. Mr. James Neilson read from the *Glasgow Herald* of 8th October, 1919, the notice of the death of Miss Miller, daughter of Hugh Miller. Mr. Neilson drew attention to this as an interesting link with the memory of the great Scottish geologist. Dr. Gregory, F.R.S., thereafter gave a lecture on the "Rift Valleys of Africa." Dr. Gregory, who had recently returned from East Africa, where he revisited many of the scenes of earlier exploration, pointed out the difference between a valley formed by erosion and one formed by step faulting. The Jordan valley is a fine example of such on a grand scale, and from their resemblance to the well-known deep cracks or rifts which are a feature of the surface of the moon, Dr. Gregory has named such valleys rift valleys. By means of a series of photographs and maps shown by the lantern, the lecturer gave a detailed description of the features of the great earthquake rifts that extend continuously from the Jordan valley down to the Red Sea, and end at the south of Tanganyika. The abruptness of the sides of parts of these rifts as well as the step faulting was well shown by the slides, and the lecturer explained the waterlessness of parts of the country as due to this drainage.

Professor Grenville Cole, who took part in the discussion, suggested that these rifts had probably been formed rapidly enough to be catastrophic.

Mr. Stark, referring to Dr. Gregory's remarks on the glaciation of many parts of equatorial Africa, asked the lecturer how this was reconciled with the view that the glacial period in the North Hemisphere was accompanied by a warm period in the south.

Dr. Gregory, in reply, referred to the summit of Mount Kenia on the Equator being above the snow line, and that the extended ice cap of the glacial period caused such a disturbance of the prevailing winds as to lead to heavy precipitation of snow on the higher parts of Africa. In reply to Professor Cole, he gave some facts observed by

Digitized by Google

the engineers of the Uganda Railway as to the instability of the floors of these great valleys.

Mr. TYRRELL referred to rift valleys observed by him in a recent visit to Spitsbergen.

A hearty vote of thanks was accorded to Dr. Gregory.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, 13TH NOVEMBER, 1919.

The second meeting of the sixty-second Session was held here this evening—Mr. G. W. TYRRELL, *Vice-President*, in the chair.

Mr. James Neilson, having declined the Honorary Membership of the Society, was, on proposal by Mr. Macnair and Mr. Stark, elected a Life Member.

The following were elected members of the Society:—

Major Allan Stein, M.C., and Mr. John Weir, proposed by Mr. Macnair and Mr. Wallace; Mr. Edward J. A. Stewart, M.A., B.Sc., proposed by Mr. Begg and Mr. Duncanson.

The Reports of Council, Finance, and Library were read by Messrs. Duncanson, Begg, and Sinclair, and were adopted on the motion of Mr. Stark, seconded by Mr. Young.

The office-bearers for the Session were next proposed as follows:—

Vice-President for three years—Mr. James L. Begg, proposed by Mr. P. Macnair and Mr. R. W. Dron.

Members of Council for three years—Mr. A. Wallace, proposed by Messrs. Macnair and Sinclair; Mr. Alex. Stevens, M.A., B.Sc., proposed by Messrs. Begg and Duncanson; Mr. Arthur Shute, proposed by Messrs. Stark and Begg; Mr. D. N. MacArthur, B.Sc., proposed by Messrs. Roberts and Stark.

As Editors of the *Transactions*—Mr. G. W. Tyrrell and Mr. D. B. Duncanson.

On the motion of Mr. Neilson, seconded by Mr. Stark, these gentlemen were declared duly elected.

Mr. JAMES NEILSON then exhibited specimens of Galena from Tyndrum and Derbyshire, and also made some interesting remarks on the veins of this mineral in these districts.

Mr. G. V. WILSON, H.M. Survey, then read a paper on "Some Scottish Ore Deposits." Mr. Wilson discussed chiefly the occurrence of Lead Ore, and especially in the district of Leadhills. The earliest reference goes back as far as 1120, and Sir David Lindsay gave a charter to the monks of Wanlochhead about 1350. From that time the output of lead increased until in 1500-1600 the Leadhills were producing lead in considerable quantity, £100,000 worth having been recorded in three months. The ore worked at first was scattered in the moraine drift, where streams had washed away the finer matter.

Digitized by Google

It was not until later that the veins were discovered. These originate in the igneous rocks, and do not travel far into the country rock. The district is cut by numerous parallel Felsite dykes, indicating a large reservoir of igneous rock. Mr. Wilson discussed at some length the different views as to the formation of the veins. The paper was illustrated by a large number of beautiful mineral specimens exhibited by Mr. Henderson and also by lantern slides. It is intended to publish this paper in the *Transactions*. A vote of thanks was accorded to Mr. Wilson and to Mr. Henderson.

JAMES L. BEGG.

SOCIETY'S ROOMS, 207 BATH STREET, 11TH DECEMBER, 1919.

The third meeting of the sixty-second Session was held here this evening—Mr. JAMES L. BEGG, *Vice-President*, in the chair. The Minutes of last meeting having been read and adopted, Mr. E. C. Bailey, M.C., B.A., F.G.S., Edinburgh, was, on the proposal of Mr. P. Macnair and Mr. M. M'Gregor, accepted as a member of the Society. At this meeting there was an attendance of 32.

Mr. JAMES ANDERSON exhibited specimens of Pyrites, Galena, and Blende from the same district, with a specimen of Slate which showed the gradual production of Pyrites due to infiltration by water, and made some remarks on the occurrence of metalliferous veins.

Mr. G. W. TYRRELL exhibited some interesting rocks, minerals and fossils, brought by him from Spitsbergen.

A lecture was then delivered by Mr. PETER MACNAIR, F.R.S.E., F.G.S., on "East and West," an exposition of the Carboniferous Problem. The correlation of the Carboniferous rocks of the East with those of the West is a problem to which Mr. Macnair has brought a highly specialised knowledge of stratigraphy and endless patience in research. So high an authority as Mr. Carruthers has declared the problem insoluble, but its difficulties have only further stimulated Mr. Macnair to attempt its solution. The Carboniferous rocks are a threefold system, consisting of the Carboniferous Limestones, the Millstone Grit, and the Coal Measures. The lecturer made use of a series of elaborate charts and maps, and brought forward the evidence which has convinced him that these rocks can be correlated East and West. He compared in considerable detail the Limestones as correlated by him from the West, and from Midlothian, Kirkcaldy, St. Monans, Dunbar, and Berwick-on-Tweed. The whole subject is a highly technical one, appealing chiefly to the expert, and will be best studied in publication. Mr. Neilson and Mr. John Smith made some remarks, and on the motion of the Chairman a vote of thanks was offered to Mr. Macnair for his able and interesting lecture. The lecture was illustrated by a number of lantern slides.

PETER MACNAIR.

Digitized by Google

SOCIETY'S ROOMS, 207 BATH STREET, 8TH JANUARY, 1920.

The fourth meeting of the sixty-second Session was held here this evening—Mr. PETER MACNAIR in the chair. The Minutes of last meeting were read and adopted. Mr. Alex. D. Garven, proposed by Mr. George Dunn and Mr. G. W. Tyrrell, was duly elected a member; while Mr. William E. Swinton and Mr. Eric Dow, proposed by Messrs. C. M. Leitch and G. W. Tyrrell, were elected Associate Members.

Mr. G. W. TYRRELL then delivered a lecture entitled "Recent Developments in Geology of Spitsbergen."

After a brief account of the history of our knowledge of Spitsbergen, the discovery of which is generally attributed to the Dutch in 1596, and to whom the name Spitsbergen is due, the lecturer gave an account of the geology of the island, or rather archipelago. Whalers and trappers were early attracted to the island and its adjoining seas, but the present attraction of the country is its mineral wealth. The first coal-bed was discovered 300 years ago, and a British company began mining in 1904, near the mouth of Advent Bay, and Longyear City, opposite to the British mine, is American property, acquired in 1904.

The main geological features are the Block-faulted mountains showing horizontal strata, and most of the systems are represented. In the western mountains no fossils have yet been found, but in Bear Island fossils of Silurian age have been dug. Broadly speaking, there are two geological divisions. Along the west and north lie old rocks thrown into folded mountains which show the sharp weathered peaks which give the island its name. The eastern part shows newer rocks faulted into the block systems already mentioned. The old rocks contain ores, and the later rocks contain coal. The coal belongs to three ages—Carboniferous, Jurassic, and Tertiary. The latter coal is of excellent quality, and occurs in several seams from 3½ to 7 feet thick.

Mr. Tyrrell described in considerable detail the main features of the rocks and their fossils, and in conclusion gave in a series of stages the main phases in the geological story of Spitsbergen, enabling his audience to watch the growth of the island from the period when sands and clays were laid down on an Archæn foundation to the last uplift which gave the present raised beaches, fjords, and crossed faults.

Dr. GREGORY and Mr. WORDIE took part in the discussion, which turned chiefly on climatic changes and the origin of the Spitsbergen coal, which Professor Gregory thought might be due to accumulated drift wood, such as is seen along the present shores of the island. A hearty vote of thanks was awarded to Mr. Tyrrell for his most interesting address.

PETER MACNAIR.

Digitized by Google

SOCIETY'S ROOMS, 207 BATH STREET, 12TH FEBRUARY, 1920.

The fifth meeting of the sixty-second Session was held here this evening—Mr. PETER MACNAIR in the chair. The Minutes of last meeting were read and adopted. Miss Sarah Peacock and Miss Agnes Meldrum, M.A., proposed by Mr. M'Lean and Mr. D. B. Duncanson, were duly elected members of the Society. Mr. James Stark proposed that a sum of £10 be devoted to the purposes of the Library for the current year. This was seconded by Mr. Wyse and approved.

Dr. ROBERT KIDSTON, F.R.S., *President*, then delivered a lecture on "Asteroxylon Mackiei from the Old Red Sandstone Chert of Rhynie, Aberdeenshire." In this lecture, the third which Dr. Kidston has given to the Society on the plants of the Rhynie Chert-beds, he presented the results of the researches of Professor Lang and himself on a plant remarkable for the four-arned cross presented by its Xylem when seen in transverse section, hence the generic name Asteroxylon proposed for it. This, it will be remembered, makes the fourth plant from this bed, viz., Rhynia Gwynne Vaughnii, Rhynia major, Hornea lignieri, and Asteroxylon Mackiei. By a magnificent series of microphotographs showing the structure of the plant so perfectly that it was difficult to realise one was not looking at fresh material, Dr. Kidston explained in detail the structure of this primitive plant. Like the other three plants, it grew from a rhizome with hair-like roots, had no leaves, and the sporangia were borne on the ends of the dichotomous branches. In the discussion which followed, Dr. Gregory commented on the light these researches would throw on the origin of a land flora, and Dr. Ellis made some remarks on the fungi preserved in the petrifaction.

JAMES L. BEGG.

SOCIETY'S ROOMS, 207 BATH STREET, 11TH MARCH, 1920.

The sixth meeting of this Session was held here this evening—Mr. JAMES L. BEGG in the chair. The Minutes of the last meeting were read and adopted. Mr. COLIN M. LEITCH, B.Sc., who with Mr. Alex. Stevens and Mr. Raeburn crossed Spitsbergen last summer with the Scotto-Spitsbergen Expedition, delivered a lecture describing some of the geological features noted during that journey. The lecture was illustrated with a number of lantern slides, and on the motion of Mr. Begg, Mr. Leitch was warmly thanked for his address. Mr. Tyrrell, Mr. Stevens, Mr. Stark, and Mr. Begg took part in the discussion that followed.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 8TH APRIL, 1920.

The seventh meeting of the sixty-second Session was held here this evening—Mr. PETER MACNAIR, F.R.S.E., *Vice-President*, in the chair.

Digitized by Google

Miss Edith A. Scobie and Mr. Charles M'Kinven, proposed by Mr. G. W. Tyrrell and Mr. D. B. Duncanson, were elected ordinary members of the Society. Mr. TYRRELL, in the absence of Professor Gregory, read an obituary notice by him of the late Professor Charles Lapworth, F.R.S., in which the special services of Lapworth to the problems of Scottish geology were recalled. Mr. Macnair pointed out that admiration for Lapworth's work on the geology of Scotland must not be allowed to obscure the work of Nicol, who must get full credit for having furnished the key to the riddle of the Highlands.

Mr. ROBERT DUNLOP then read two papers (1) "A Note on the Woodmill Chitons," in which he argued that all the Chiton plates found at Woodmill belong to one species; (2) "Notes, with Lantern Illustrations, of Burrows and Tracks of some Invertebrates from the Carboniferous." Mr. Dunlop also exhibited these four rare Nautili, crassiventer, multicarinatus, cyclostomus, oxystomus.

JAS. STARK.

SOCIETY'S ROOMS, 207 BATH STREET, 13TH MAY, 1920.

The eighth meeting of the sixty-second Session was held here this evening—Mr. STARK in the chair. The Minutes of the previous meeting were read and adopted. Mr. J. S. Young was proposed and seconded as an Associate Member, and the Rev. M. A. Frater as an Ordinary Member by Mr. G. W. Tyrrell, seconded by Mr. Duncanson.

Mr. J. M. WORDIE, M.A., B.Sc., Geologist with the Weddell Sea Party of Sir Ernest Shackleton's Expedition, then gave a lecture entitled "An Outline of Antarctic Geology." The lecture was illustrated by maps and lantern pictures. A vote of thanks was awarded Mr. Wordie for his lecture.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 20TH AUGUST, 1920.

A joint meeting of the Councils of the Archæological, Natural History, and Geological Societies was held here this evening—Mr. PETER MACNAIR in the chair. The meeting was called at the suggestion of Mr. James Neilson to discuss ways and means of trying to solve the problem of the origin of the Auld Wives' Lifts.

Mr. NEILSON said that until excavations were made to get more evidence there was no good in further discussion. He proposed that a permanent excavation down to the base of the stones be made under the direction of a skilled archæologist, say Mr. Mungo Buchanan.

Mr. STARK pointed out the difficulty of draining the bog round the stones, and did not think excavations on such a scale would be worth while. A series of bores taken with the lifts as centre would be adequate.

Digitized by Google

Mr. LUDOVIC MANN pointed out the need for an investigation of the whole surroundings from the great interest of the place, both geologically and archæologically. He believed that the top of the upper stone had been flattened by man, and spoke of the large ring, which he maintains is penannular and pre-historic. The stone inclines to the east. On the sandstone near by he has found two cup markings joined by a gutter, and also an oblique cut socket. He suggests that these were an astron. meridian station.

Mr. STEVENS suggested making a careful survey to prepare sections showing the shape of the valley floor and the thickness of the peat. Mr. Dron supported this. It was finally agreed that the Natural History and Archæological Societies be asked what sum they would be prepared to spend on this problem. In the meantime Messrs. Stevens, Stark, Duncanson, and Begg undertook to make a preliminary survey to determine chiefly the possibility of drainage.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 14TH OCTOBER, 1920.

The opening meeting of the sixty-third Session was held in the Rooms at 7.30 p.m.—Professor MACNAIR in the chair.

Professor GREGORY, D.Sc., F.R.S., delivered a lecture entitled "The Future of Oil Supply." Professor Gregory said the recent sharp rise in the price of petrol had been explained either as simple profiteering or as a warning that the demand for mineral oil was growing much faster than the supply. The temptations to reckless use were powerful. During the past twelve months the increase of the world's shipping was estimated at 9 per cent. on tonnage; but the increase in the number of ships driven by oil and motors had been 35 per cent. The United States before the war had 4,000,000 motor vehicles. It was estimated that next year the number would be 10,000,000, and that American shipping would require 60,000,000 barrels of oil. In 1918 the United States supplied 69·15 per cent. of the total world's production of mineral oil. The British Empire (including Egypt and Persia) produced 3·80 per cent.; but it consumed three times as much and was largely dependent on the United States. Experts said that the American present output could not be maintained for more than five years, that some of its chief oilfields would be exhausted within a couple of decades, and that its oil consumption was growing so fast that it would soon have to import instead of export oil. The prospects of increasing the oil supply were dependent on the development of existing fields and the discovery of new fields. The field from which the greatest increase might be expected was Mexico, and its yield was predicted to surpass that of the United States. Galicia was estimated to contain another 100,000,000 tons. The Russian yield was on the decline before the

Digitized by Google

war, but the output had kept up remarkably. Among new fields Venezuela was the most promising, but little was generally known of the results of recent prospecting there. A second enlargement of the supply might come from the discovery of oil in areas where search had been discouraged by the predominant theory of the formation of oil pools. The most convenient reservoirs occurred where the beds were bent into arch-like upfolds; but in some of the most productive fields the oil did not come from the arches or "anticlines," but from the downfolds (synclines). The search for oil had been in some areas on the wrong track owing to the predominance of the upfold theory. Aerial navigation would be seriously handicapped if in twenty years' time the petrol supply had been reduced by the reckless use of mineral oil. The geological prospects of the world's supply warned us that it would soon be necessary to consider the prohibition of the use of oil for purposes for which other fuels were available.

The lecture was fully illustrated by lantern slides.

The Chairman intimated that at the second meeting on 11th November it would be moved that the subscription be increased from 10s. to 15s., and for ladies from 7s. 6d. to 10s.

R. KIDSTON.

SOCIETY'S ROOMS, 207 BATH STREET, 11TH NOVEMBER, 1920.

The second meeting of the sixty-third Session was held here this evening—Dr. ROBERT KIDSTON, F.R.S., *President*, in the chair.

Mr. Robert Hay, Royal Technical College, proposed by Professor Gregory and Professor Macnair, was duly elected a member of the Society. The following office-bearers were then elected:—

As President for three years—Professor Macnair, F.G.S.

As Vice-President for three years—Mr. Harry R. J. Conacher.

As Members of Council for three years—Mr. Donald Patton, M.A., B.Sc.; Mr. Matthew Brodie, Dr. David Ellis, Mr. Duncan Smith.

Honorary Librarian—Mr. William Sinclair. Honorary Secretaries—Messrs. Duncanson and Tyrrell; and as Editors of *Transactions*, the Honorary Secretaries.

Mr. JAMES BEGG moved that the subscription be made 15s., and 10s. for ladies. Mr. JAMES STARK seconded, and it was unanimously carried.

Professor MACNAIR then took the chair, and in thanking the Society for the honour of his election as President, expressed his continued interest in the Society's welfare.

Mr. HARRY R. J. CONACHER, *Vice-President*, then delivered a lecture entitled a "Sketch of Petroleum Geology." Mr. Conacher referred to the early oil drillers as priding themselves in their practical skill and despising the guidance of the scientific geologist, and that only in recent years has the geology of petroleum become well enough understood to enable the oil driller to benefit from the guidance of

Digitized by Google

the scientist. The first oil wells, opened in Pennsylvania fifty years ago, were the start of what was now a gigantic industry. A rough guide in the early days in districts known to be oil-bearing was given by the fact that the oil fields were longer than broad, and that they had a certain orientation. But this proved of no assistance when new fields had to be found. Hunt's theory that anticlinal crests were the usual oil reservoirs had proved useful until the proper conditions had been determined. It is essential that a porous bed to act as reservoir be present with non-permeable beds above and below. The best containers are Sandstones, and the contained matter may be Gas, Oil, or Water. The Sandstone's capacity depends on the size and shape of the grains, and on the presence of Cement. Large grains give good storage spaces, and conversely. Limestone, with abundant cracks, are very favourable, but Shales are less satisfactory unless fissured. Oolitic limestones are good, and igneous rocks, if fissured, occasionally act as storages. Besides storage beds, there must be material suitable for conversion to petroleum. The theories that explained the mineral Hydrocarbons as due to the action of water on metallic Carbides had now been given up. It was now recognised that the Petroleum was due to the decomposition of vegetable matter, and also to some extent animal matter. It was also now recognised that the anticline theory did not fit every case. Some of the greatest wells were in mid-continental states, with strata almost horizontal. Some gushers occurred on the flanks of anticlines. In America attempts had been made to locate lenticular sandbanks at great depths which acted as storehouses of oil. In Texas drilling had been done on the tops of domes of salt, the drilling in certain cases being carried to great depths. In Mexico various great flows for a short time had been obtained from highly fissured limestone, whereas in sand there was a steady flow for a long time. The meaning of the association of Brine and Petroleum was not yet understood. The oil on the surface of the Brine was probably pressed up, and the coming of Brine indicated approaching exhaustion. In general only a fraction of the oil is recoverable. The lecture concluded with a reference to the mining of oil sands for extraction of Petroleum in Alsace.

In the discussion, Professor GREGORY, Mr. HARRISON, and Mr. DRON took part. Professor MACNAIR afterwards exhibited Corals from the Blackbyre Limestone of Auchren Pit, Lesmahagow.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 9TH DECEMBER, 1920.

The third meeting of the sixty-third Session was held here this evening—Professor MACNAIR in the chair.

The following new members were duly elected to the Society:—

Mr. Edward M. Melville, M.A., B.Sc., proposed by Mr. D. N. MacArthur and Mr. C. J. Gregory; Mr. J. B. Drinnan, proposed by

Digitized by Google

Mr. C. J. Gregory and Professor Gregory; Mr. J. A. Rodger, proposed by Professor Macnair and Mr. MacArthur; Mr. John Henderson, proposed by Professor Macnair and Mr. R. W. Dron.

Mr. JAMES NEILSON delivered a lecture entitled "Notes of a Tour in Algeria and Tunisia." Mr. Neilson, who had recently returned from an extensive journey in North Africa, gave a most interesting account of what he had seen in Algeria and Tunisia. Over 100 lantern slides were shown, those of the Rummell Gorge in particular being of high geologic interest. Mr. Neilson had much to say about the archæology of the districts he had visited, and described the grandeur of the Roman remains as more impressive witness of the power of that people than anything that could be now seen in Rome itself.

The lecture was much appreciated, and on the motion of the Chairman, a hearty vote of thanks was awarded to Mr. Neilson.

JAMES L. BEGG.

SOCIETY'S ROOMS, 207 BATH STREET, 13TH JANUARY, 1921.

The fourth meeting of the sixty-third Session was held here this evening—Mr. JAMES BEGG, *Vice-President*, in the chair.

The following were elected members of the Society:—Mr. D. G. Ramsay, M.A., B.Sc.; Mr. George Ross, B.Sc.; Mr. Alex. Nicholson; Miss Ethel D. Currie, B.Sc.—proposed and seconded by Miss Agnes T. Neilson and Mr. James Begg.

Mr. ALEX. STEVENS, M.A., B.Sc., then gave an account of the work done by a few members in making some observations at the Auld Wife's Lift. The work done consisted in laying out two levels at right angles, N. to S. and E. to W. These in turn were marked off at intervals of 15 feet, and bores were made through the bog to the bed rock. In several cases the length of the borer, 4 feet, was insufficient to reach the bottom. From these rather few data Mr. Dron had made a plan and section which shows that the stones lie in a shallow rock basin, and that excavations on their site would necessitate the cutting of a channel southward deep enough to drain this basin to the depth of the rock surface. Mr. Stevens thought that this would involve more trouble and expense than was worth while at present. He also considered that the large circle cut in the surface of the stone did not bear the interpretation that some archæologists put on it, because there was no indication that it was any older than the initials carved by vandals on the stone near by. Mr. NEILSON thought that there was nothing to be said until excavations had been made, and he repeated his offer made at a Council meeting to bear with Mr. Stark the experse of any such excavations. Mr. DRON explained that a complete survey of the site would require a large number of bores, and that the present scrap section might contain errors due to isolated boulders. Mr. STARK did not think anything important was to be learned by excavations. On the surrounding

Digitized by Google

rock surfaces the striae were by no means distinct, and the sandstone below the bog was likely to be so much decomposed by contact with water-logged peat that no marks would be seen. This decomposed rock was seen at the bottom of the little drainage stream and ditch. He described large stones on the Strathblane road which he thought were counterparts on a smaller scale of the Lifts. Mr. Neilson considered this beside the points. Such stones might be due simply to gravitation and not to ice movement. Mr. TYRRELL thought it should be determined whether the peat went below the stones, but Mr. STARK pointed out that stones of such weight would long ago have sunk through the bog to the rock surface below. Mr. BEGG described the 4th Stone which had once been part of the eastern supporting stone.

Mr. STEVENS then read a paper entitled the "Economics of Spitsbergen." Economic interest in this archipelago began in the fourteenth century, when whale, seal, and walrus hunting began. In later times interest has centred round the minerals of Spitsbergen. These were said to be coal, iron, oil, gypsum, marbles, molybdenum, silver, gold, asbestos, rubies, and diamonds. The possible resources of the country in each of these was discusssed in detail by Mr. Stevens. Gypsum of good quality occurs in great quantities and of excellent quality for plaster, but when the price obtainable plus carriage was compared with gypsum from other countries, it was seen that the gypsum of Spitsbergen would not make a paying proposition. The Teritiary (coal) is a fine black bituminous coal, containing 81 per cent. carbon. It outcrops on the west coast 700 feet uphill, and can be easily loaded. It is of great value, and is over 1 metre thick. The Jurassic seam has carbon 76 per cent., while the Carboniferous Coal is of poor quality, and difficult to mine. The coal and also the marble loses much of its value on account of frost cracks, often so numerous as to cause the material to break up on thawing. In Mr. Stevens' opinion the coal is the only Spitsbergen mineral of economic importance. Messrs. Kerr, Tyrrell, and Dron took part in the discussion, and a vote of thanks was awarded to Mr. Stevens. The lecture was illustrated with numerous lantern slides.

JAS. STARK.

SOCIETY'S ROOMS, 207 BATH STREET, 10TH FEBRUARY, 1921.

The fifth meeting of the sixty-third Session was held here this evening—Mr. JAMES STARK in the chair.

Mr. DONALD PATTON, M.A., B.Sc., gave some interesting descriptive notes on some fossil plants brought by Mr. G. W. Tyrrell from Spitsbergen.

Mr. G. W. TYRRELL then delivered a lecture on the "Glaciers of Spitsbergen." [*See page* 2.]

G. W. TYRRELL.

Digitized by Google

SOCIETY'S ROOMS, 207 BATH STREET, MARCH, 1921.

The sixth meeting of the sixty-third Session was held here this evening—Mr. G. W. TYRRELL, A.R.C.Sc., in the chair. Professor P. MACNAIR, F.G.S., *President*, delivered the Presidential address. His subject was "The Physical Conditions under which the Deutozoic Rocks of Scotland were deposited," dealing in the first place with the Old Red Sandstone formation. [*See page* 105.]

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 14TH APRIL, 1921.

The seventh meeting of the sixty-third Session was held here this evening at 7.30.—Professor MACNAIR in the chair.

Mr. E. B. BAILEY, M.C., B.A., F.R.S.E., delivered a lecture entitled the "Structure of the South-West Highlands of Scotland." The lecture was illustrated by several large charts and diagrams, and also numerous lantern slides. In the course of his lecture Mr. Bailey brought forward evidence to prove the following propositions:—

1. The Ardrishaig Phyllites and overlying Loch Awe Group constitute together the highest structural assemblage of the S.-W. Highlands.
2. The Loch Awe Group is probably of later date than the Ardrishaig Phyllites.
3. Beneath the level of the Ardrishaig Phyllites there is a marked contrast on the two sides of the Loch Awe Syncline: the rocks emerging along the Islay Anticline on the one side are different from those emerging along the Cowal Anticline on the other.
4. The explanation of this discrepancy is afforded at Ben Lui, where members of the Cowal Assemblage begin to pass beneath the Loch Awe Syncline and then turn back upon themselves in a recumbent fold.
5. When considered critically it is found that the upper limb of the Ben Lui fold is largely replaced by a thrust serving as a base for the Loch Awe Nappe.
6. The Basal Thrust of the Loch Awe Nappe separates the lithologically similar Ardrishaig and Ben Lawer's Groups, and thus solves the long-realised difficulty that the Ardrishaig-Ben Lawer's Complex (hitherto considered as a stratigraphical unit) has three markedly different margins.

Professor GREGORY complimented Mr. Bailey on the clearness with which he had expressed his views, and remarked that having examined much of the evidence in the field with Mr. Bailey, there could be no doubt that however time and further work might modify the views of geologists on this subject, Mr. Bailey's work would always

Digitized by Google

stand out as a notable contribution to Scottish geology. The simplicity of some of the older views compared with Mr. Bailey's was noteworthy but it was almost axiomatic that nature is never simple. Professor MACNAIR remarked on the mental and bodily equipment required in a research such as this, and also contrasted some of the simpler ideas held by himself with the complexity of Mr. Bailey's. Mr. TYRRELL expressed appreciation of Mr. Bailey's work.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 13TH OCTOBER, 1921.

The opening meeting of the sixty-fourth Session was held here this evening—Professor MACNAIR in the chair. Miss Emily Stobo, M.A., B.Sc., proposed by Mr. Duncanson and by Mr. Tyrrell, was duly admitted to membership of the Society.

The opening address was delivered by Dr. WALCOT GIBSON, H.M. Geological Survey, who took as his subject "The New Yorkshire Coalfield." This coalfield lies on the moors of Yorkshire and Derbyshire. The Trent forms its eastern border, and a large part of the field has water access to the sea. Assuming that 50 per cent. can be got out, the coal in the new field is estimated at 14,000 million tons, or, with the present fields, a total of 41,000 million tons, as against 21,000 million for Scotland. The Barnsley or Tophard is the most important seam, and is practically the only one at present worked in the new field. The marine beds accompanying it can be matched on both sides of the Pennines, and the seam covers at least 600 square miles. Its thickness varies from 3 to 11 feet, and is on the average 5 feet thick. The coalfield has been explored by numerous bores, and its structure is complicated by faults and folds, and the Triassic sandstones from 500 feet to 2000 feet thick are full of water, and will prove formidable obstacles in working. Between the deposition of the highest Coal measures, the Keble beds, and the deposition of the Permian and Trias, the Carboniferous rocks were folded and fractured, and denuded to an extent equal to the denudation on the west and south of the Pennines, so that on west and south the new formations fill deep hollows in Carboniferous rocks. In the discussion Mr. R. W. DRON suggested that the English Coals belong to a higher series than those of Scotland. The problems presented by them also to the geologist and engineer he considered were simpler than the corresponding problems in Scotland. In Scotland we might take it that all our coalfields were known.

Mr. M'GREGOR pointed to the reaction that this work would have on Scottish geology. Mr. MACNAIR emphasised the importance of fossils in working out limits of deposits, and referred as a case in point to the value of the marine beds in correlating the different parts of the field. Dr. Gibson, in reply, stated that the conditions of de-

Digitized by Google

position in England, Scotland, and Westphalia were so different that it was absurd to attempt to compare them. The Coal Measures of Scotland were far below those of England, and no Upper Coals existed in Scotland. The lecture was illustrated by large diagrams.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 10TH NOVEMBER, 1921.

The second meeting of the sixty-fourth Session was held here this evening—Professor PETER MACNAIR, *President*, in the chair.

Mr. C. J. GREGORY read a paper on "Parallel Roads at Loch Tulla." [*See published paper, page* 91.]

In the discussion Mr. DAVID KERR said that although he had been at Loch Tulla he had never seen any trace of parallel roads on the hill. Mr. ALEX. STEVENS pointed out that such traces on a hill might be seen with difficulty unless one chanced to have the right angle and point of view. Mr. MURRAY M'GREGOR, on the other hand, referring to the coincidence of two papers on the same subject being read by Mr. Gregory and Mr. Bailey in Glasgow and Edinburgh within the same week, said that the "roads" were easily seen. Mr. Bailey had described two roads at 1041 feet and 830 feet. Mr. TYRRELL, referring to the enormous glacial lakes that had been traced over the present site of the great lakes of North America, said that conditions must have obtained at that time quite unlike the present day, because nowhere in glacial regions had we anything approaching the magnitude of these lakes. The President also spoke some words in compliment to Mr. Gregory, and congratulated him on his first paper to the Society.

Exhibits—Mr. R. W. DRON exhibited a fine Pseudo-Artifact from Spitsbergen, and Mr. JAMES STARK showed vitrified stone from the fort of Craigpatrick and Barytes Crystals from Algerian Sahara. Mr. DUNCANSON exhibited vitrified stone from Glen Nevis fort.

JAMES L. BEGG.

SOCIETY'S ROOMS, 207 BATH STREET, 8TH DECEMBER, 1921.

The third meeting of the sixty-fourth Session was held here this evening—Mr. JAMES BEGG, *Vice-President*, in the chair.

Mr. Alex. Steven, Technical School, Kilmarnock, proposed by Mr. Robert Macmillan and Mr. Duncanson, was elected a member of the Society.

The election of office-bearers was then proceeded with as follows:—

As Vice-President for three years—Mr. R. W. Dron, M.Inst.C.E., F.R.S.E.

Digitized by Google

As Members of Council for three years—Mr. Walter Dixon, Mr. J. J. Hunter Johnston, Mr. C. J. Gregory, Mr. M. M'Gregor, M.A., B.Sc.

Mr. G. W. TYRRELL then gave an address on his recent work in South Arran. Mr. Tyrrell pointed out that south Arran is probably unique as a field for the study of igneous intrusive geology. As Harker has drawn attention to the occurrence in Skye of Basalt and Felsite, with Basalt in patches through the Felsite, and often the two rocks mixed to an intermediate type, so also in south Arran. This is well seen in the Ross and at Squiler, where the sequence runs—Basalt, Felsite, Basalt, Felsite, Dolerite, Sandstone, Felsite, Dolerite, Sandstone. Mr. Tyrrell believes that these great intrusions took place in successive stages, forming what is called a Cedar Tree Laccolite, well seen in Monamore Glen. On one aspect the thinned-out edges of the intrusion can be separately traced, whereas on the other aspect the intrusion is apparently in one mass. Examination in detail, however, shows an absence of the variation in size of crystals which one would expect in a massive intrusion. One of the interesting details of Mr. Tyrrell's lecture was the working out of the age of the intrusion at King's Cross, where there have been successive intrusions of Clauchland Sill, then Granite and Felsite, next Pitchstones, and lastly Basalt.

Mr. DONALD PATTON, in congratulating Mr. Tyrrell, drew attention to the new light this work threw on such massive intrusions as Tinto, where for 2000 feet we have a fine-grained Felsite. Mr. BEGG, Mr. YOUNG, and Mr. M'LEAN complimented Mr. Tyrrell on his most interesting paper, and on Mr. Begg's motion a hearty vote of thanks was accorded.

PETER MACNAIR.

GLASGOW UNIVERSITY BOTANY LECTURE ROOM, 12TH JANUARY, 1922.

The fourth meeting of the sixty-fourth Session was held here this evening at 8 p.m.—Professor F. O. BOWER in the chair. The Society met jointly with the Glasgow University Botanical and Geological Societies. The following new members' names were on the billet:—Mr. James Phemister, M.A., B.Sc.; Mr. John Weir, M.A.; and Mr. James Holmes. These were proposed by Miss A. T. Neilson and Mr. G. W. Tyrrell, and fall to be elected at the fifth meeting.

Dr. ROBERT KIDSTON, F.R.S., delivered a lecture on "The Fossil Plants of the Rhynie Chert Bed," discovered by Dr. Mackie. Dr. Kidston had already given three lectures to this Society on the four plants of the Chert, so that a certain amount of the lecture had already become known to our members. Dr. Kidston, however, had many new section photomicrographs to show, and a good deal of new and highly interesting information with regard to fungal parasites of the plants. The preservation of the structure in most of the slides was

Digitized by Google

almost beyond belief. One of the new photographs showed a stoma in plan, and the lecturer pointed out how in all the vast time that has elapsed since the Middle Old Red Sandstone no perceptible change has taken place in the structure and appearance of the stomata.

In proposing a vote of thanks, Dr. GREGORY referred to the distinguished researches of Dr. Kidston in palæobotany, and said that the Rhynie work rounded up a long list of discoveries of which Scottish Geology was proud.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 9TH FEBRUARY, 1922.

The fifth meeting of the sixty-fourth Session was held here this evening—Professor MACNAIR, *President*, in the chair. The following new members were elected:—Rev. S. J. Ramsay Sibbald, proposed by Mr. Alex. Sutherland and Professor Macnair, and Mr. Alex. Gardner, proposed by Professor Macnair and Mr. Duncanson. Thereafter Mr DONALD PATTON, M.A., B.Sc., read a paper entitled "An Example of River Action and its Bearing on Plant Distribution." [*See page* 80.]

Mr. DIXON, Mr. TYRRELL, and Mr. MACNAIR made some remarks on the paper, and a vote of thanks was accorded to Mr. Patton.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 9TH MARCH, 1922.

The sixth meeting of the sixty-fourth Session was held here this evening—Professor P. MACNAIR, *President*, in the chair. Papers were read by Messrs. E. M. ANDERSON, M.A., B.Sc., and H. H. READ, B.Sc., A.R.C.Sc., officers of H.M. Geological Survey.

Mr. ANDERSON'S paper dealt with his own observations of the Schiehallion Country. By means of a large coloured map and list of the rock sequences he explained in a lucid manner the general conclusions he had come to in regard to the build of that part of Perthshire, particularly in reference to the rock systems on the two sides of the great quartzite ridge of Schiehallion. In commenting on the paper, the President referred to the complexity of the subject and to the perennial interest of the problems presented by the geology of the Highlands.

Mr. READ'S paper, which was also highly technical in character, dealt with what he calls "Contaminated Magmas of Aberdeenshire." These are magmas which have incorporated sedimentary material as distinct from a true primary magma. Mr. Read was able to show that in north-east Scotland magmas of noritic character may by contamination give rise to abnormal rocks containing Cordierite, Spinel, Sillimanite, Biotite, Hornblende, Andesine, Orthoclase, Garnet,

Digitized by Google

Quartz. Mr. Read has studied rocks, however, that show normal granitic structure, and he has put forward a hypothesis to show how the sedimentary Xenoliths may have been removed. The Xenoliths, while in suspension in the liquid magma while it is basic, gradually receive heavy material from the magma, hence the denser Xenoliths sink in the liquid, and a clean, apparently normal rock is left. He has put forward, after long chemical analysis, a principle of selective assimilation to group and generalise these changes. He is thus able to show that, starting with a primary basalt magma, we may conceive how by gravitation and assimilaton all the at present known igneous rocks may have been produced.

In the discussion Mr. TYRRELL referred to the great importance of these new ideas in igneous geology put forward by Mr. Read, and remarked that these discoveries supported his contention that Scotland was a unique country for the study of igneous phenomena. Mr. Read's paper was illustrated by numerous lantern views and photo-micrographs.

Mr. W. H. COLEMAN exhibited a specimen of Benotite from Alberta, Canada. This is a fine clay which has found a variety of industrial uses, such, for example, as acting as a carrier for essences and oils of therapeutic value for use in poulticing. This preparation is sold under the name of Antiphlogiston.

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 13TH APRIL, 1922.

The seventh meeting of the sixty-fourth Session was held here this evening—Mr. G. W. TYRRELL in the chair.

Mr. Alex. Cullen, 14 Hamilton Park Terrace, Glasgow, proposed by Mr. E. J. Edwards and Mr. Duncanson, was duly elected a member of the Society.

The President then read the second part of the Presidential address on the physical conditions under which the Deutozoic Rocks of Scotland up to the Carboniferous were deposited. The address will be published in the new volume of *Transactions*. [*See page* 105.]

Mr. G. W. TYRRELL read a paper by Mr. John M'Gregor on "Certain Fissures on Benmore, Kilmun." The Presidential address was illustrated by lantern slides. [*See page* 69.]

PETER MACNAIR.

SOCIETY'S ROOMS, 207 BATH STREET, 11TH MAY, 1922.

The eighth meeting of the sixty-fourth Session was held here this evening—Professor MACNAIR in the chair. Dr. ARCHIBALD BARR read a paper on "Columnar Structure," and Dr. JAMES FRENCH read

Digitized by Google

a paper on "Fractures in Homogeneous Media." Both papers were illustrated.

Dr. BARR referred to the paper read to the Society in 1877 by Professor James Thomson, in which the concretionary theory was shown to be untenable. He also referred to Mallet's paper of 1875, in which columnar structure was explained as due to contraction on cooling, but he was of opinion that this explanation was unsatisfactory. An explanation had occurred to him in 1879, of which he had not hitherto given any published account. He explained the comparatively uniform size of the transverse dimensions of the columns by consideration of the bending action on the material adjacent to a crack that had already formed, and the tendency of that part to assume its original unbent condition.

[For Dr. French's paper, *see page* 50.]

The Secretary intimated that by the will of the late Mr. James Christie, his maps, lantern slides, and rock sections had been bequeathed to the Society.

Digitized by Google

Digitized by Google

ABSTRACT

OF THE

TREASURER'S ACCOUNTS.

Digitized by Google

ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDED 30TH SEPTEMBER, 1921.

CASH ACCOUNT.

RECEIPTS.

To Balance on hand 30th Sept., 1920:—			
Balance in Bank, ...	£21 18 6		
Cash in Treasurer's hands, ...	7 14 10		
Cowie Prize Fund, ...	2 10 0		
		£32 3 4	
,, Subscriptions:—			
Gentlemen—107 at 15/, ...	£80 5 0		
Do. 1 at 10/, ...	0 10 0		
Ladies— 7 at 10/, ...	3 10 0		
Arrears— 4 at 10/, ...	2 0 0		
Associate— 1 at 2/6, ...	0 2 6		
		86 7 6	
,, Interest on Funds Invested:—			
5½ per cent. Exchequer Bonds, ...	£8 12 6		
4 per cent. Funding Loan (Mr. Jas. Neilson Gift), ...	2 16 0		
		11 8 6	
Cowie Prize Fund:—			
5½ per cent. Exchequer Bonds, ...		5 15 0	
,, Income Tax refunded (Funding Loan), ...		1 4 0	
,, Sale of *Transactions*, ...		1 7 4	
		£138 5 8	

EXPENDITURE.

By Library:—			
New Books and Magazines, ...			£7 15 0
,, Subscriptions:—			
Palæontographical Society, ...			1 1 0
Scottish Marine Biological Association, ...			1 1 0
Natural History Society (Lantern), ...			1 1 0
,, Cowie Prize Fund:—			
Glasgow University, Interest to Dec., 1920,	£2 17 6		
Royal Technical College, Interest to Dec., 1920, ...	2 17 6		
			5 15 0
,, Administration:—			
Printing and Postage of Billets, ...	£13 8 2		
Rent, Insurance, Light, and Attendance, ..	11 19 0		
Hon. Secretary and Treasurer's expenses, ..	2 5 11		
			27 13 1
,, Cash in Hand, ...	£0 16 9		
,, Cash in Bank, ...	93 2 10		
			93 19 7
			£138 5 8

Digitized by Google

LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1921.—To Balance to Credit, ...	£229	15	0	Sept. 30, 1920.—By Balance from last Account, ...	£229	15	0
	£229	15	0		£229	15	0

COWIE PRIZE FUND.

Sept. 30, 1921.—To Glasgow University, one-half Interest to Martinmas, 1920, ...	£2	17	6	Sept. 30, 1920.—By Balance from last Account, ...	£103	15	0
,, Royal Technical College, one-half Interest to Martinmas, 1920, ...	2	17	6	,, One year's interest to December, 1920, ..	5	15	0
,, Balance to Credit, ...	103	15	0				
	£109	10	0		£109	10	0

BALANCE SHEET.

To Life Subscription Account, ...	£229	15	0	By Investments:—			
,, Cowie Prize Fund and accrued Interest, ...	103	15	0	£350 Exchequer Bonds, 1925, 5½ per cent., including Cowie Prize Fund, ...	£250	0	0
,, Capital, ...	610	9	7	Funding Loan (James Neilson's Gift), 4 per cent., ..	100	0	0
				,, Property:—			
				Books in the Library, Microscope, Bookcases, &c., ..	500	0	0
				,, Cash in Bank, ... £93 2 10			
				,, Balance Cash on Hand, ... 0 16 9			
					93	19	7
	£943	19	7		£943	19	7

GLASGOW, 9*th November*, 1921.—Examined, compared with relative Vouchers and Securities, and found correct, the Balance in Treasurer's hands being Sixteen Shillings and Ninepence stg.

ARCH. MACINTYRE, F.S.A.A.,
ALEX. M'LEAN, } *Auditors.*

Digitized by Google

THE GEOLOGICAL SOCIETY OF GLASGOW.

Office-Bearers, 1922.

President—

Prof. Peter Macnair, F.R.S.E., F.G.S.

Vice-Presidents—

James Begg. H. R. J. Conacher.
R. W. Dron, F.R.S.E., M.I.M.E.

Members of Council—

Alex. Wallace.
Arthur Shute.
Donald Patton, M.A., B.Sc.
Dr. Ellis.
J. J. Hunter Johnston.
C. J. Gregory.
Alex. Stevens, M.A., B.Sc.
D. N. M'Arthur, B.Sc.
Matthew Brodie.
Duncan Smith.
Walter Dixon.
M. M. M'Gregor, M.A., B.Sc.

Honorary Treasurer—

James Begg, The Elms, Mount Vernon.

Honorary Librarian—

William Sinclair, 47 Oswald Street, Glasgow.

Honorary Secretaries—

David B. Duncanson, B.Sc., Training College, Jordanhill, Glasgow
G. W. Tyrrell, A.R.C.Sc., University, Glasgow.

Digitized by Google

Digitized by Google

PUBLICATIONS OF THE SOCIETY.

TRANSACTIONS.—Demy 8vo.

Vol. I. Part 1.—The Geology of the Campsie District. By John Young, LL.D., F.G.S. (3rd edition, revised), 2/
——— Part 2.—The Phenomena of the Glacial Drift of Scotland. By Sir Archibald Geikie, F.R.S. (*Reprint*), (*Out of Print*).
Vol. II. Part 1.—Papers on Local and Theoretical Geology, (*Out of Print*).
——— Part 2.— Do. do. do. ,, ,,
——— Part 3.— Do. do. do. - - - 4/6
Vol. III. Part 1.— Do. [contains "On Geological Time." By Lord Kelvin, F.R.S.], - - - 4/
——— Part 2.— Do. [contains "On Geological Dynamics." By Lord Kelvin, F.R.S.], - - 4/
——— (Supplement)—On the Carboniferous Fossils of the West of Scotland. By John Young, LL.D., F.G.S., and James Armstrong, - - (*Out of Print*).
Vol. IV. Part 1.—Papers on Local and Theoretical Geology, - - 3/
——— Part 2.— Do. do. do. - - 3/
——— Part 3.— Do. do. do. - - 3/
Vol. V. Part 1.— Do. do. do. - - 4/
——— Part 2.— Do. [contains "Geological Climate." By Lord Kelvin, F.R.S.], - (*Out of Print*).
Vol. VI. Part 1.— Do. [contains "The Internal Condition of the Earth." By Lord Kelvin, F.R.S.], 4/
——— Part 2.—Papers on Local and Theoretical Geology, - 4/
Vol. VII. Part 1.— Do. do. do. - 5/
——— Part 2.— Do. do. do. - 5/
Vol. VIII. Part 1.— Do. do. do. - 5/
——— Part 2.— Do. [contains "Polar Ice Caps and their Influence in changing Sea Levels." By Lord Kelvin, F.R.S.], - - - - 5/
Vol. IX. Part 1.—Papers on Local and Theoretical Geology, (*Out of Print*).
——— Part 2.— Do. do. do. ,, ,,
Vol. X. Part 1.— Do. do. do. - - 6/6
——— Part 2.— Do. do. do. - - 7/
Vol. XI. Part 1.— Do. do. do. - - 6/
——— Part 2.— Do. do. do. - - 7/

All parts in hand up to this date may be had by members at a reduced price.

——— (Supplement)—Drift Deposits of Ayrshire. By John Smith, - - - - - - - 3/
Vol. XII. Part 1.—Papers on Local and Theoretical Geology, - - 5/
——— Part 2.— Do. do. do. - - 5/
——— Part 3.— Do. do. do. - - 5/
——— (Supplement)—Natural History of Scottish Zeolites. By J. G. Goodchild, F.G.S., - - - 2/6
Vol. XIII. Part 1.—Papers on Local and Theoretical Geology, - 5/
——— Part 2.— Do. do. do. - - 5/
——— Part 3.— Do. do. do. - - 5/
Vol. XIV. Part 1.— Do. do. do. - - 5/
——— Part 2.— Do. do. do. - - 5/
——— Part 3.— Do. do. do. - - 5/
Vol. XV. Part 1.— Do. do. do. - - 5/
——— Part 2.— Do. do. do. - - 7/6
——— Part 3.— Do. do. do. - - 7/6
Vol. XVI. Part 1.— Do. do. do. - - 7/6
——— Part 2.— Do. do. do. - - 7/6
——— Part 3.— Do. do. do. - - 7/6
Vol. XVII. Part 1.— Do. do. do. - - 7/6

JUBILEE VOLUME.

HISTORY OF THE GEOLOGICAL SOCIETY OF GLASGOW, - - - 4/6

GEOLOGY OF THE CLYDE DRAINAGE AREA.

Compiled for the Meeting of the British Association, Glasgow, 1901. Demy 8vo, paper boards, - - - - - 1/; interleaved, 1/6

Copies of the above from the Hon. Libn., Mr. WM. SINCLAIR, at the Society's Rooms, 207 Bath Street, Glasgow; *or through any Bookseller.*

Digitized by Google

TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY

OF GLASGOW.

VOL. XVII.—PART II.

1924-1925.

GLASGOW: PUBLISHED BY THE SOCIETY,
AT ITS ROOMS, 207 BATH STREET.
FEBRUARY, 1925.

William Hodge & Co., Ltd.,] [*Printers, Glasgow.*

PRICE 7s. 6d.

Digitized by Google

Digitized by Google

TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

No. I.—The Red Sandstones of Toward. By Mr. James Stark.

The Red Sandstones of Toward skirt the Firth of Clyde for a distance of 3½ miles to the south-west of Innellan Pier, and are cut off from the Highland schists by the great Boundary Fault, of which a very fine exposure may be seen on the shore at the gate of Toward Castle.

The sandstones are generally composed of minute well-rounded grains of quartz, with, in certain places, a considerable amount of felspathic dust, cemented together by ferric oxide. They dip in various directions generally at low angles, with a good deal of cross bedding, and contain occasional bands of conglomerate or breccia, mainly of vein quartz and Highland schists, sometimes a few inches thick, but often represented by only a few scattered pebbles.

No organic remains have been discovered, but in places there are to be seen numerous small spheres, from which the red colouring matter has been discharged, the oxide being converted into a silicate of iron. Here and there the surface of the sandstones is roughened by a network of sharp ridges enclosing between them cup-like depressions, which are probably sun cracks subsequently filled with drifted sand, and have consequently resisted denudation better than the original deposit, as the sand grains would be more likely to be drifted into the cracks than the lighter felspathic dust.

A well-marked feature is the occurrence of quite a number of white siliceous limestones or cornstones, conformable to the sandstones, and sometimes as much as 5 to 6 feet thick. Some of these are pure and crystalline, almost like marble,

Digitized by Google

while others, especially the thinner ones, are a mixture of sand and carbonate of lime in varying proportions.

The position of these strata is probably near the top of the Upper Old Red Sandstone, and not far below the overlying Calciferous series.

Deposits similar to these are now being laid down in other parts of the world, which may throw light on the origin of the Toward Sandstones.

Skirting the north-west coast of Africa, the Atlas Mountains, with a breadth of 200 miles, and an altitude of 7000 feet, extend from the Atlantic to Tunis, a distance of 1200 miles. They thus effectively cut off the Hinterland from the sea, and, by condensing any aqueous vapour in the air, render arid the low-lying plains of the Sahara to the south-east. That region has consequently become a desert of shifting, wind-blown sand, where the grains are rounded and worn much smaller than they could be by aqueous action, and the felspathic elements are reduced to impalpable dust; so much so, that when the Sirocco blows from the desert, it carries the dust right across the mountains to the Mediterranean. Meantime, streams from the mountains replenish the supply of fresh material, and occasional torrential rains bring down stones from the screes on the hill slopes and spread them over the adjacent sands. Much other material, especially carbonate of lime, is also brought down in solution by the streams, which, during the rainy season, form temporary shallow lakes, called shatts by the Arabs, in depressions in the sands. These shatts have no outlet to the sea, and, being soon evaporated, the minerals held in solution are deposited on their bottoms.

In some of the drier parts of India, an impure cornstone, called Kankar, is fairly common, forming concretionary lumps in the surface soil, due probably to the evaporation of surface water holding carbonate of lime in solution. These are collected, and when burnt make an excellent hydraulic mortar.

It may here be said that the late Dr. Murray defined arid conditions as those where the annual rainfall was less than 10 inches.

Digitized by Google

Applying this to the Toward Sandstones: while there is evidence that in Devonian times a shallow southern sea extended from Cornwall eastward through Belgium and Germany to Poland, there is also evidence of an extensive Continental area in the north-west, due probably to the uplift of the Caledonian Range before the beginning of that period. This elevated tract seems to have extended from Northern Europe to Eastern Canada, and from its denudation the strata of the Old Red Sandstone were laid down on its south-eastern flanks, as evidenced by the occurrence of similar deposits in Russia, Scandinavia, Spitzbergen, Scotland, and Canada. This lofty barrier would shut off the land behind it from the sea, and produce the same results of aridity and inland drainage as the Atlas Range has done in the case of the North African Sahara, within comparatively recent geological times.

There is no doubt that the Lower Old Red Sandstone originally extended far to the north of the Boundary Fault, and must have contributed, as well as the Highland schists, to the materials which now compose the Toward Sandstones. In weathering, the andesites would provide solutions of silica, and of lime and iron carbonates from their component minerals, the latter soon to be changed by contact with the the air into the insoluble ferric oxide, in the absence of decaying organic matter.

Had this been present, it would have abstracted the oxygen from the solution, and reconverted it into the soluble carbonate, as pointed out by the late Mr. Goodchild in a lecture to this Society in 1887. The red calciferous shales, mined for making terra-cotta bricks, &c., in Upper Lanarkshire, are frequently diversified by light-coloured patches, and, on splitting them open, one finds portions of lepidodendra, &c., which had reduced the ferric oxide, and discharged the colouring matter in their immediate neighbourhood, indicating, probably, the transition from an arid climate to the humid conditions of the Carboniferous period. Under the latter conditions, the ferrous carbonates, when carried in solution into shallow lagoons, were concentrated in the form of siderites, thus producing our clayband or

Digitized by Google

blackband ironstones, according to the predominance of mud or bituminous matter at the bottom of the lagoon.

Turning now to Toward, in certain parts of the area we find sandstones composed of minute well-rounded, polished, and apparently wind-blown grains of quartz, strangely interstratified with occasional irregular patches of course subangular breccia, while in other places the sandstones are sufficiently argillaceous to develop sun cracks and are probably the sites of temporary lakes, into which rare particles of vegetable matter would be carried by streams from the hills. These would get water-logged and sink to the bottom, and in decaying would reduce the ferric oxide in the adjacent sediments as far as their influence extended—the indirect and only evidence of organic existence in the sandstones.

These phonomena, taken together, appear to point to conditions of deposit similar to those which now exist in the Northern Sahara on the flanks of the Atlas Range.

Digitized by Google

No. II.—The Geology of a Composite Intrusion at Bennan, South Arran. By J. V. Harrison, B.Sc.

The Composite Dyke at Bennan, South Arran.

There occurs in the extreme south of the island of Arran a composite intrusion composed of three sheets. The prominent cliffs produced by the weathering out of the intrusion have been remarked, in their references to Bennan Head, by most writers on Arran for a century. Inland from the sea the position of the dyke is marked by raised barren ground, for the intrusion is more resistant than the sandstones and marls through which it cuts. It is accurately mapped on the colour-printed geological map of Arran published by the Geological Survey of Great Britain in 1910.

The intrusion cuts steeply through the Keuper marls and sandstones (Gregory, page 179), which are gently baked, whilst it is cut in turn by numerous basic dykes which throughout the Western Isles are regarded as being of late Tertiary Age. Since the Mesozoic was a period of volcanic quiescence in Scotland, the dyke is a product of early Tertiary volcanic activity.

The two outer sheets are quartz "dolerite" and the central one enclosed between them is quartz porphyry. At its northern termination where the dyke approaches the main road the central sheet pinches out and the two other sheets coalesce into one. The "dolerite" thus forms a sheath enclosing the porphyry. The outer margins of the sheath show chilled edges due to rapid cooling, but the junction between the "dolerite" and the porphyry is ragged, with apophyses of the latter intruded into the former. Fragments of "dolerite" in all stages of absorption are contained in the quartz porphyry, which therefore was intruded after the "dolerite." No chilled edge was observed between the two members dyke. The quantity of "dolerite" picked up by the later central sheet is greatest where the intrusion as a whole has its greatest thickness, at which point the southern "dolerite sheet" is also at its maximum

Digitized by Google

development. The mixture is so intimate here that a volume of homogeneous mixture rock has resulted.

The average width of the basic sheets is from ten to fifteen feet, but at the Struey Water is some 300 feet wide. The acid rock from where it pinches out rapidly widens to 300 feet, and then gradually increases to over 1000 at the Struey Water.

Petrography.

Rocks, similar to these occurring at Bennan, have been described in detail from Skye (Harker, pages 197-223) and Bute (Smellie, pages 121-139). In both of these islands the age relations of the components are the same as those found here. Corstorphine (pages 455-469) gives a short account of the Bennan rocks in a general treatise on the rocks of South Arran.

The outer sheets of the dyke are composed of quartz "basalt" or "dolerite," for which Professor S. J. Shand suggested the term granodolerite. It is a dark bluish rock containing a profusion of microscopic quartz and felspar crystals set in a fine-grained to medium groundmass. At the edge of the sheets in contact with the Keuper sandstone, the body of the rock is vitreous in appearance, but the bulk is coarser grained until in the thickest part of the dyke most of the constituent minerals can be distinguished by the naked eye. But the grain has little influence on the composition of the rock as a whole, which retains a nearly constant specific gravity of 2·77, except in the glassy margin, of which the specific gravity is 2.

Plagioclase, quartz, augite, and magnetite are the main constituents, with chlorite, hypersthene, and apatite occurring occasionally. The texture varies. The rapidly cooled marginal facies is either a dark brown glass replete with microlites and small crystals of felspar, augite, and magnetite, or else a cryptocrystalline mass, profusely dusted with spears and cubes of magnetite. In the bulk of the rock is developed a typical granulitic texture matching sections figured by Teall (Pl. 12) from the Tynedale Dyke. A micropegmatitic base, however, is widely disseminated

Digitized by Google

through the normal rock in place of a felspathic one as figured and described by Judd in the type granulitic dolerite (page 68). By gradual stages the granulitic rock passes into a sub-ophitic variety in the thickest part of the southern outer sheet, but even here micropegmatite is present to a small extent. In all these modes the rock is pseudo-porphyritic owing to the quartz and felspar xenocrysts occurring.

Plagioclase is the predominating mineral. It occurs chiefly as microlites or imperfectly formed laths, but there are also occasional phenocrysts and numerous xenocrysts. One slide exhibits the separate stages in the crystallisation from minute microlites, through skeletal and "swallow-tailed" forms to perfectly formed laths, though generally the terminations on the small prismatic felspars tend to be ragged. The determinable laths are composed of andesine to acid labradorite. The few phenocrysts are fresh, cracked, and zoned, with centres of labradorite and margins of oligoclase. Albite, carlsbad, and occasionally pericline twinning were remarked.

The oligoclase and albite-oligoclase xenocrysts present the characteristic absorption forms of turbidity and rounded outline. They are dusted with spherical, feathery, or irregular inclusions, sometimes scattered through the whole crystal and sometimes in orderly zones, similar to those figured and described from the Cnoc Càrnach composite sill (Harker, page 220). These symptoms of corrosion are approximately as far advanced for crystals lying in the granulitic rock as for those frozen into the chilled edge. On the other hand, in the thickest part, the xenocrysts of felspar have undergone still greater wear and tear, their size being reduced and the inclusions multiplied. The plagioclase crystals are liable to fracture along cleavage planes, and in one slide augite and felspar are intergrown to give a tessalate effect, alternate cleavage parallelograms of felspar being replaced by cleavage rectangles of augite.

The groundmass of the granodolerite is in general cryptocrystalline and very like that in the quartz dolerite from near Kilsyth (Tyrrell, pages 98-99), and in places the grain is sufficiently coarse to allow the micropegmatite to be re-

Digitized by Google

solved, and the component quartz and orthoclase recognised under the microscope.

Quartz is abundant as it occurs in the micropegmatite and as xenocrysts. In general these have a diameter up to 7 mm., and show the rough usage they have received by the deep bays cutting into their rounded forms. They are fringed with aureoles of augite prisms. The size of the reaction rim is about the same for individuals occurring in either the granulitic rock or the chilled edge, but is increased in the thickest part of the basic sheet, and the blebs are consequently smaller.

The augite present in the granodolerite is a pale yellow variety in which no pleochrism could be distinguished. Multiple twinning is common, but diallagic striation was not seen. In the granulitic rock it occurs as equidimensional grains, but occasional idiomorphic crystals also occur, and in the sub-ophitic type anhedral plates abound. It forms the prismatic crystals encircling the quartz blebs, and in one case was found intergrown with a plagioclase phenocryst.

Orthorhombic pyroxene, hypersthene, is not common in the bulk of the rock. It occurs principally in the basic rocks exposed in the Struey Gorge, and is present in the form of euhedral, pleochroic, highly-refracting crystals with low interference colours. It is invariably surrounded by a narrow fringe of deep green chlorite, due to decomposition.

All varieties of the basic rock contain magnetite. Swarms of small cubes up to ·01 mm. diameter and spears of this mineral occur in the chilled marginal facies, whilst in the normal rock the cubes reach the size of ·1 mm. in diameter. These crystals abut on and sometimes enclose felspar laths. The coarser sub-ophitic rock contains larger crystals which are constricted in growth by both augite and plagioclase crystals.

Apatite occurs in acicular crystals embedded in the micropegmatite.

Chlorite is sparingly present as a product of decay of the orthorhombic pyroxene and to a lesser extent of the monoclinic augite. In the former case it is dark green, and in the latter pale green.

Digitized by Google

The quartz porphyry is a fine-grained yellowish rock, resplendent with numerous porphyritic crystals of glassy quartz and fresh felspars up to 15 mm. in diameter. It is a rock very similar to the quartz porphyry of Corrie Gills and South Bute. The average specific gravity is 2·49.

To microscopic examination it reveals quartz and felspar in microgranitic relations, although a few slides show micrographic intergrowth of the two minerals. Sparse cubes of magnetite together with a very little pale green chlorite make up the mafic constituents. The quartz phenocrysts in the microgranitic groundmass retain their crystallographic outlines closely, the hexagonal basal sections showing but slightly rounded angles. Inclusions are scanty. Where the groundmass is micrographic, the quartz phenocrysts no longer display regular contours, but are surrounded by zones of micropegmatite in which the quartz is in optical continuity with the nearest phenocryst. Drusy cavities occur in which quartz crystals appear with facies well developed, whilst their roots are intergrown with orthoclase as micropegmatite. In one of these the rare cleavage of quartz occurs, showing the cleavage planes parallel to the pyramidial facies of the crystal.

Both orthoclase and oligoclase occur as phenocrysts. They are present as well formed uncorroded crystals.

Intermixing of the granodolerite and the quartz porphyry along the line of their contact, although occurring continuously, is extensive only where the basic southern sheet has its widest extension, viz., in the Struey Water. In the mixture rocks produced, the mineral content differs not in kind but in proportion, excepting that no hpyersthene was found.

In the normal junction xenoliths of granodolerite, varying in size from large boulders to small pebbles, are enclosed in the porphyry. Sections cut to contain partly xenolith and partly surrounding rock exhibit acidification of the xenolith. The augite granules are decomposed into chlorite, quartz, and magnetite, and the larger augites have their edges replaced by similar products of decomposition. The basification of the porphyry is less apparent, but fresh phenocrysts of quartz and oligoclase occur lying side by side with

Digitized by Google

xenocrysts derived from the basic rock, and showing the effects of corrosion which they have suffered during their captivity in the granodolerite.

The abnormal mixture rock which occurs near the Struey Water due to the slower cooling is a homogeneous, even-grained, non-porphyritic rock in which small black crystals of augite can be discerned by the naked eye. Microscopically the rock is seen to be made up mainly of micropegmatite and rectangular kaolinised orthoclase crystals up to 1 mm. in diameter. Fresh bladed euhedral augite up to 3 mm. long is present as the other common constituent. This augite granophyre has a specific gravity of 2·55.

The southern sheet and the mixture zone are cut by numerous acid segregation veins of varying thickness. In the hand specimen these are light grey in colour and of fine even grain, and are composed of granophyre made up of quartz and orthoclase in microgranitic relations, with sparse grains of magnetite. Perfect hexagonal prisms of limonite are numerous.

A thin vein of tachylite 2 inches wide cuts the sill about 500 yards east of Struey Water. It comforms closely to tachylites found in other western islands of Scotland (Judd and Cole, page 459). It is a black glass containing small crystals and microlites of plagioclase, augite, and magnetite.

The other intrusions cutting the composite dyke are chiefly normal olivine dolerites, but in two instances it is cut by porphyritic felsite.

Petrology.

From the above discussion it is evident that the granodolerite was first intruded through the Keuper sandstones as a normal dyke. Along the central plane of weakness in this dyke, and while it was still only partly cool the quartz porphyry forced its way. The composite intrusion completed cooling before the phase of intrusion which produced the olivine dolerite and felsite dykes commenced.

Smellie suggested the mixing of a normal Tertiary basaltic magma with a granitic one to account for the rock types found in the composite sill in South Bute, and such a

Digitized by Google

hypothesis will serve to explain the facts observed in South Arran. In the basaltic magma intratelluric crystallisation had produced the zoned plagioclase crystals and some augite before mixture with the granitic one was effected. In the latter both quartz and felspars had crystallised as phenocrysts before the mixing, which must have occurred just before intrusion of the granodolerite, because the interval between mixture and intrusion was of the same order as that which intervened between intrusion and cooling to the temperature at which viscosity inhibited molecular interchanges. But these intervals were sufficient for the groundmass of the granodolerite to have become homogeneous by the production of micropegmatite from the mixing of the magmas, and for the chemical reactions to unite the more basic and acid molecules, to the elimination of orthosilicates and to the grouping of the bases round the quartz crystals, the acid nuclei, as augite aureoles. The pyroxene girdles in turn protected the quartz xenocrysts and caused them to be less rapidly absorbed than the felspars, which had no such protection. This second period ended with the squeezing out of the last dregs of the molten quartz felspar eutectic to form the acid segregation veins which solidified in cracks produced in the cooling dyke.

The occurrence of this type of composite intrusion is never far from a large granite mass, and where one such intrusion as this occurs it is seldom alone in the district. This is the case in Skye, and the Bennan dyke is one of similar intrusions grouped round the Arran granite, other members of which are the composite sill of South Bute, and the intrusions of Tormore (Cleiteadh nan Sgarbh), Drumadoon Point, and Tor Dubh Beag.

The mechanics of this peculiar sequence of intrusion and magmatic intermixing is still not understood, and what Mr. Harker said of this group in Skye cannot be bettered for those of Arran, viz., that "they belong to a point of time accurately separating the plutonic phase from that of the minor intrusions," and mark the beginning of the final stages of a volcanic epoch.

Digitized by Google

BIBLIOGRAPHY.

Corstorphine, G. S.
1895. "Ueber die Massengesteine des sudliches Theiles des Insel Arran, Schottland." *Tscherm. min. petr. Mitth.*, vol. xiv., pp. 455-469.

Gregory, J. W.
1914. "Permian and Triassic Rocks of Arran." *Trans. Geol. Soc., Glasgow*, vol. xv., pp. 174-187.

Harker, A.
1903. "The Geology of North Arran." *Mem. Geol. Surv., Scotland*, pp. 114-117.

1904. "Tertiary Igneous Rocks of Skye." *Mem. Geol. Surv., Scotland*, pp. 197-223.

Judd, J. W., and Cole, G. A. J.
1883. "Basalt Glass of the Western Isles." *Q.J.G.S.*, vol. xxxix., pp. 444-465.

Judd, J. W.
1886. "Gabbros, Dolerites, and Basalts of Tertiary Age in Scotland and Ireland. *Q.J.G.S.*, vol. xlii., pp. 49-97.

Smellie, W. R.
1913. "Tertiary Composite Sill of South Bute." *Trans. Geol. Soc., Glasgow*, vol. xv., pp. 121-139.

Teall, J. J. H.
1888. "British Petrography." Pl. 12.

Tyrrell, G. W.
1909. "Geology and Petrology of the Intrusions of the Kilsyth-Croy District, Dumbartonshire." *Geol. Mag.*, Dec. 5, vol. vi., pp. 299-309, 359-366.

Digitized by Google

No. III.—Megatherium Bones Found at Quishuarcancha, Peru. By Mr. J. A. W. Murdoch.

The bones here described were found in a cave about 2000 feet from the coal-mine at Quishuarcancha, in latitude 10° 22′ S., longitude 76° 16′ W., on the Atlantic watershed of the Cordillera of the Andes, at an altitude of about 12,500 feet above sea-level and 150 feet above the present stream bed. This altitude is at present the upper limit of scrubby trees. The formation is Lower Cretaceous.

The cave was rediscovered only recently, but it had been inhabited at some unknown previous date. The floor of the cave is at present only 10 feet from the roof, and is covered with river-wash to a depth of 28 feet. The original hollow was, therefore, 38 feet in height. The outer width is 26 feet, and its depth 20 feet. The river-wash consists of a reddish matrix with sub-angular boulders, some of which were so large as to require blasting. This deposit shows no sign of stratification, and the floor of the cave is of sandy limestone. The filling appears to have been carried in during a flood or mud-rush, for it shows no evidence of normal river deposition.

This cave is evidently a large pothole eroded at a time when the stream flowed 150 feet above its present level. Although now only 20 to 30 feet wide, it was, no doubt, a large river during the time the Andean ice-cap was melting.

The mouth of the cave was almost completely concealed by brushwood, and was rediscovered by one of our staff while out shooting. The site is locally called "Puchi-paca-pana," that is, the "place where one can hide something."

The head of the large femur (Plate II., first bone on left) was found projecting slightly from the old floor, and was mistaken at first for a skull. Pursuing excavations; we found quite near the surface the remains of five human skeletons in poor preservation. Two of these were of children. Two of the skulls have been sent to Lima University Museum in the hope that their age may be determined. They are undoubtedly comparatively recent, and show high foreheads without the artificial flattening fairly common in skulls of the pre-Inca

Digitized by Google

period. They may possibly represent victims of the bandits who traditionally are supposed to have inhabited this cave fifty or sixty years ago, but this is a matter of uncertainty.

Further excavation has yielded in all about six hundredweight of bones and fragments of bones. These were found scattered irregularly through the wash, and they represent several different animals. The only bones found in something like their original sequence were some half-dozen flattened vertebræ which, I think, represent part of the tail of a Megatherium. Two characteristic Megatherium jaw-bones were found, but no complete skull, though some of the fragments might be pieces of a skull. A fairly complete horse-like skull and several teeth were also found, which Professor J. J. Bravo, of Lima, tells me resemble those of an extinct American horse, Para-Hipparion, and that this is the first finding of such remains in Central Peru, though similar remains were found near Cuzco by the Yale University Expedition.

In this connection it is interesting to note that Darwin, in "The Voyage of the Beagle," chapter V., says that he found in Bahia Blanca, in the Argentine, in 1833, bones of Megatherium, and of an extinct kind of horse in the same deposit.

Did the Megatherium, which had no front teeth, and is supposed to have browsed on trees, live alongside of the horse, which, judging from its teeth, was no doubt a grass eater? And was this part of Peru, which is now just a succession of precipitous ravines with nearly barren ridges between, at that time a rolling pampa country considerably near sea-level, with a more luxuriant vegetation? On the question of large animals not requiring a very luxuriant vegetation, see Darwin, *loc. cit.*

Were our Megatherium bones previously embedded in a deposit farther up-stream, which was subsequently eroded and the bones washed down to the pothole in which they rested? Possibly. But it seems more likely that the carcases were washed into this pothole, where they milled round and round till they rotted, and were then covered up by a flood, which thickened to the consistency of plum-porridge, the plums being sub-angular boulders.

Such mud-rushes, known as "huaicos," are quite common

Digitized by Google

in this Cordillera in the rainy season, and cost the Central Railway of Peru thousands of pounds annually. Although it may be quite sunny in the Rimac Valley, up which the railway runs, a rainstorm in the mountain tops, four or five miles away, will send a " huaico " rolling down the stream beds. These " huaicos " come down quite slowly, say, at five or six miles an hour, in the flatter parts of the stream beds, with a wave-front four feet high or thereabout, the boulders seeming to float in the mud. They fill up the channel under a culvert or small bridge, perhaps partially blocked by tree trunks and boulders, and carry off a pair of 25-ton girders as if they were matches. The " huaicos " are always preceded by small floods of muddy water.

Now, it seems feasible to suppose that if a partially decomposed carcase were milling round in a pothole, a flood of half an hour's duration would tend to tear it to pieces, and that the following " huaico " or mud-rush would fill up the pothole. The resulting deposit would show no stratification.

This is what, I think, happened in the Puchi-paca-pana cave some time ago, since when the stream has eroded its bed 150 feet. I may mention that the total depth of the ravine at this point is about 1700 feet. The lowest four feet of wash in the cave yielded no bones, and I am informed that there was no recognisable line of demarcation between this part and the wash above it. Near where we found the horse-like skull, that is, about 22 feet below the original floor of the cave, we found some small limb-bones about $\frac{1}{8}$ inch in diameter. Close by were two lower jaw-bones, somewhat over 1 inch long, with needle-pointed canine teeth over $\frac{1}{4}$ inch long. I think that these belonged to a bat. They have been sent to Lima for identification.

There are no bats now living at this altitude, but a few leagues lower down the valley small bats are a perfect pest, as they suck blood from one's horses and mules when corralled at night, and if the bite is on the withers, it is liable to develop into a saddle-sore. They also attack people, and I have been bitten in the nose by one of them.

After we had cleaned out this cave we found another, separated from the first by a rib of rock two feet thick. This second

Digitized by Google

cave had at one time been inhabited, but the mouth had been completely closed by a "huaico" which had come down a little gully on the right. The material of this mud-rush was quite unlike the old river-wash, and contained no bones. Under it and on the top of the old river-wash we found remains of fires, and also two copper wires with perforated heads, which may be teeth of an old Inca comb.

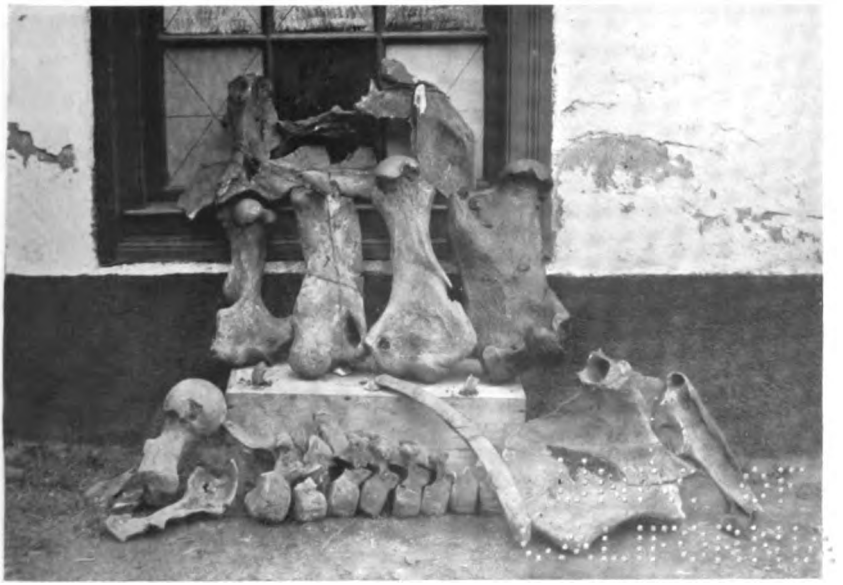
This second cave is 34 feet wide and 18 feet long. We excavated it to a depth of 26 feet below the former floor. It yielded no large bones, and only one fragment that I could recognise as belonging to a Megatherium femur. The bones from this second cave include the skull of a small rodent 3 inches long, bones of small horse (?), many limb-bones about 4 inches long, hollow and very fragile, either of a bird or very large bat, and a sharp claw 2·5 inches long, perhaps of a puma. These remains have not yet been examined by any scientist. By comparing the lengths of the limb-bones and vertebrae of our Megatherium with the plate in Dana, I think this specimen must have been about 12 feet long, exclusive of tail, and 4 feet across the stern. A good description of Megatherium will be found in Encyclopædia Britannica, 11th edition. Plate No. 1 shows the pelvis of Megatherium in process of excavation. By comparison with the foot-rule, it will be seen that it measures about 42 inches across. The squares of paper indicate where other important bones were found.

Plate No. II. shows other bones of Megatherium. The box on which the four large bones rest is 25½ inches long. The large femur on the right is 21½ inches long. The large fragment of femur on the left was the first-found bone mentioned before, which, projecting slightly from the floor of the cave, was mistaken for a skull. Two pieces of the characteristic rectangular teeth of Megatherium are shown resting on the box.

Digitized by Google

Pelvis of Megatherium in process of excavation. Foot-rule shows size—about 42 ins. Small squares of white paper show where other important bones were found.
Note.—Foot-rule begins at 6 ins., not at zero.

Plate II.



Bones of Megatherium. The dynamite box is 24½ ins. long. The large femur on right is 21½ ins. long. The large fragment of femur on left was the first bone found—slightly projecting from original floor of cave. The finder thought it was an Inca skull. Note the two pieces of characteristic rectangular Megatherium teeth on dynamite box.

Digitized by Google

Digitized by Google

No. IV.—The Geology of Iceland: The Pioneer Work of a Scottish Geologist. By Martin A. Peacock, B.Sc., L.R.A.M., Carnegie Research Fellow, University, Glasgow.

TABLE OF CONTENTS.

	PAGE
I. Introduction,	185
II. The Werner-Hutton Controversy,	186
III. Mackenzie and the Icelandic Visit,	189
IV. Brief Outline of Icelandic Geology,	196
The Pre-glacial Formation,	198
The Inter-glacial Formation,	200
The Post-glacial Formation,	201
Tectonics,	203

I. Introduction.

Except to the student of Icelandic geology the name of Sir George Steuart Mackenzie will be unfamiliar, and of those who have read his "Travels in Iceland during the Summer of 1810,"[1] few will have had an opportunity to examine his large collection of Icelandic rocks, and none certainly, except the present writer, have been fortunate enough to be able to apply modern research methods to this interesting suite of volcanic products. Dr. G. W. Tyrrell assisted in salving the forgotten collection from the archives of the Royal Society of Edinburgh, and to him the writer would at once express his indebtedness for providing this valuable material.

The examination of this material led to a closer study of "Travels in Iceland," and many of the statements and arguments contained in the chapter entitled "Mineralogy," and in the catalogue of minerals, necessitated for their just comprehension a knowledge of the state of opinion at the end of the eighteenth and the beginning of the nineteenth centuries regarding the origin of the rocks of the earth's crust; as a result of these investigations it was concluded that as the pioneer of Icelandic geology, and as one who justly used his observations to help to overthrow the aqueous

[1] Edinburgh, 1811.

Digitized by Google

dogma of Werner, Mackenzie deserves more than half a dozen references scattered through the geological literature of Iceland.

For the better understanding of Mackenzie's work, it is proposed to devote some space to a brief account of the Neptunist and Vulcanist theories, then to consider Mackenzie's geological work, especially his visit to Iceland, and, finally, to add a very short outline of the geology of Iceland as we now know it.

II. The Werner-Hutton Controversy.

In tracing the development of every science, with the possible exception of mathematics, a turning point may be observed where its fundamental principles are finally settled, and a period of ignorance, guesswork, insufficiently founded generalities, and even wilful misrepresentations by those who had not the courage to confess ignorance, gives place to a time when ignorance is often admitted, generalities are supported by exhaustive experiments, and only sound induction is permitted. In geology we find that as late as the beginning of the nineteenth century a powerful and popular school of geologists held that all rocks, with the exception of recent indisputable lavas, had an aqueous origin, being formed either by sedimentation or by deposition from solution. In other words, but little over a century ago, such a basic idea as the aqueous or igneous origin of rocks was still a matter of hot dispute, and not until this was settled did geology reach the turning point where wild speculations as to the earth's age and early history gave way to reasonably certain estimates of the distribution of land and sea, and the nature of the climate and inhabitants of the globe in past ages.

Werner (1750-1817), whose Neptunian theory influenced geological thought for fully half a century, and many of whose terms have survived in our modern nomenclature, was created professor of mining at the small school of mines in Freiburg in 1775. To quote Lyell—"Werner's mind was at once imaginative and richly stored with miscellaneous knowledge. He associated everything with his favourite

Digitized by Google

science, and in his excursive lectures he pointed out all the economical uses of minerals; the influence of the mineral composition of rock upon the soil, and of the soil upon the resources, wealth, and civilisation of man. . . . The charm of his manners and his eloquence kindled enthusiasm in the minds of all his pupils, many of whom intended at first only to acquire a slight knowledge of mineralogy; but, when they had once heard him, they devoted themselves to it as the business of their lives. In a few years a small school of mines, before unheard of in Europe, was raised to the rank of a great university, and men already distinguished in science studied the German language, and came from the most distant countries to hear the great oracle of geology."[2]

Briefly, Werner considered the rocks of the earth's crust to be a series of concentric shells of various materials, gneiss, granite, limestone, and so forth, which had been precipitated by successive risings of a "common menstruum" or "chaotic fluid." The holo-crystalline texture of granite, for instance, was ascribed to slow crystallisation from this powerful solvent; the vitreous nature of a basaltic vein was explained as the result of such rapid separation from solution that the solid product was amorphous; and an igneous origin was denied to all rocks except those whose similarity to present-day lavas was unquestionable. We may wonder how this universal aqueous theory enjoyed the popularity it did, but when we consider that no one can observe the formation of a plutonic rock, and that the majority of mineral veins, whose constituents are practically insoluble at ordinary temperatures, are certainly deposited from solution as Werner said, the explanation seems less inconceivable.

Further, the Wernerian theory was cunningly devised to fit the Mosaic account of the beginning of the earth, and so closely was Neptunism interwoven with orthodoxy, that the two became inseparable, and must stand or fall together. This fact assured the theory of the support of many who would otherwise have shown better judgment, but at

[2] Charles Lyell, "Principles of Geology," London, 1830, vol. i., pp. 55-56.

Digitized by Google

the same time it led Werner's adherents into a serious quandary, and proved a source of strength to the opposite school. Even a casual estimate of the present rates of erosion and sedimentation, and of the advance and retreat of shore lines, made it clear that with the comparatively short time available the earth's present surface features could be explained only by postulating a series of catastrophes of which there is no parallel acting at the present day. And it was this wholesale employment of hypothetical geological agencies which contributed to undermine the strength of the Wernerian conception.

To turn now to the rival school, we find that in Britain a different line of thought had developed, one which gave the agency of subterranean heat an important rôle in the formation of rocks, and credited only such geological agencies as can be seen at work at the present time. The founder of this school was the Scottish geologist, Dr. James Hutton (1726-1797), and his followers were termed Vulcanists or Plutonists. In his "Theory of the Earth" (1795) he expressed ideas virtually coincident with those held to-day; Werner's cataclysms were discredited, the earth was given an immensely greater antiquity than that allowed by the orthodox view, thus giving time for the slow action of waves and weather to have effected the great superficial changes observable, and the igneous nature of volcanic rocks, intrusions, and plutonic masses was recognised. Only in one respect did he differ from presently accepted views, namely, in requiring the agency of modified subterranean heat to consolidate sediments which we now hold are converted to solid rock in most cases by the pressure of superincumbent strata and cementation by percolating waters.

Unfortunately for the progress of geology, Hutton clothed his ideas in rather obscure language, as a result of which he was frequently misconstrued. His opponents, themselves prone to generalisations, applied their own methods to Hutton's theory, and through them it became universally understood that the Huttonian theory implied the igneous origin of all rocks. This injustice was keenly felt by many at the time, especially by Playfair, the great mathematician.

Digitized by Google

This scientist, attracted to geology by the keen controversy of the time, impartially examined the facts, and in a volume entitled "Illustrations of the Huttonian Theory," a book remarkable for its sound scientific induction and excellent style, placed Hutton's theory in a true light, and confirmed his views by numerous personal observations in the field. With the publication of Playfair's "Illustrations" in 1802, the popularity of the Neptunists was badly shaken. With desperate ingenuity the Wernerians argued their cause, and a scientific controversy degenerated into a bitter personal strife; and, just as Galileo of old was defamed as a heretic for daring to assert that the earth was a globe, the Vulcanists and their ideas were readily connected with the infernal regions. But Neptunism was on the wane; a theory which satisfactorily explained geological appearances with no other stretch of the imagination than to conceive an immensely long period of slow development appealed more and more, and many, who a few years previously had been inflamed by the oratory of the oracle of Freiburg, forsook the ranks of the Wernerians, and adopted the tenets of Hutton.[3] Thus we see the state of affairs which obtained at the opening of the nineteenth century, the turning point in the development of geology, and shall proceed to indicate how Mackenzie helped to consolidate the rational views of Hutton by a series of observations in a country which owes its whole existence to volcanic activity.

III. Mackenzie and the Icelandic Visit.

According to the Dictionary of National Biography, George Steuart Mackenzie, the son of Major-General Sir Alexander Mackenzie, was born in 1780 and died in 1848. He succeeded to the baronetcy on the death of his father in 1796, and first became known to the scientific world in 1800, when he obtained decisive proof of the identity of diamonds with carbon by a series of experiments on the

[3] In fairness to Werner it must be emphasised that this condemnation of his work in no way applies to his most valuable contributions to mining geology.

Digitized by Google

formation of steel by the combination of diamonds with iron; in these experiments he is said to have made free use of his mother's jewels. A few years later he became a Fellow of the Royal Societies of Edinburgh and London, and ultimately president of the physical class of the former. Mackenzie's chief interest lay in geology, and under the guidance of Professor Robert Jameson, of Edinburgh, he acquired a considerable knowledge of the subject. A list of his published work includes papers on the parallel roads of Glen Roy, a paper suggesting an origin of glaciers, an account of some geological facts observed in the Faroe Islands, and "Travels in Iceland during the Summer of 1810." That his interests were not confined to geology is seen from other papers, which embrace such varied subjects as Diseases of Sheep, Taste, Phrenology, Agriculture, and three lectures on "The Insufficiency of Physical Facts for Establishing the Continued Existence of the Deity."

Jameson, we read, was at one time an ardent Neptunist, but later he frankly admitted his conversion to the views of Hutton; Mackenzie doubtless witnessed his teacher's change of opinion, and his desire to collect data bearing on the absorbing question, coupled with the curiosity to explore a little-known country, led to the formation of the plan to visit Iceland. For companions Mackenzie chose two Edinburgh gentlemen, Dr. Holland and Dr. Bright, and "Travels in Iceland" is the joint work of the three travellers, Holland providing the sections on history and literature, and on the diseases of Icelanders, Bright contributing the chapters on zoology and botany, and Mackenzie being responsible for the pages devoted to rural affairs and mineralogy. Although it is proposed to consider only this last chapter, the remainder of the book makes most interesting and often amusing reading; as an example of the latter may be mentioned the description of a ball at *Reykjavik*, at which the gentlemen "unengaged in the dance drink punch, and walk about with tobacco pipes in their mouths, spitting plentifully on the floor," or the account of the humorous horrors of a formal dinner at which Mackenzie and his companions were constrained by the strict

Digitized by Google

laws of Icelandic etiquette to exceed considerably their capacities for food and drink.

Early in May of 1810 the travellers landed at *Reykjavík*, and, in the course of the ensuing six months, made three excursions to the more accessible parts of south-western Iceland. In the first they explored the *Gullbringu Sysla*, the peninsula which forms the southern boundary of the wide *Faxafjörður*. Commencing at *Reykjavík*, where he examined the doleritic lavas and collected specimens, Mackenzie proceeded to the island of *Viðey*, on which he discovered the peculiar palagonite bearing rocks which have formed the subject of frequent discussions by later investigators; returning to the mainland the party proceeded south to *Hafnarfjörður*, crossing an area of recent basaltic lavas on the way. On Mackenzie's map, which appears in "Travels in Iceland," such areas are indicated in a blue colour, and, by comparison with Thoroddsen's geological map, it is seen that these areas always form part of larger areas mapped by Thoroddsen as Post-glacial basaltic lava. From *Hafnarfjörður* a visit was paid to *Bessastadir*, which was observed to lie on doleritic lavas similar to those surrounding *Reykjavík*. Returning to *Hafnarfjörður*, the party proceeded southwards to *Krisuvík* and the sulphur mountains, where a most interesting specimen of palagonite rock was collected; on the way a detour was made to examine a large lava cave which had been produced by the expansion of steam within the molten rock. From *Krisuvík* the travellers continued westward along the southern shore of the peninsula to *Grindavík*, and then northwards to *Njardvík* and *Keflavík*, where they again picked up the Pre-glacial doleritic lavas, which, although largely covered by more recent lavas, extend over the whole peninsula. By following the northern shore line, the travellers arrived back in *Reykjavík*, and thus completed the first excursion.

The main object of the second excursion was the investigation of the *Snæfellsnes* peninsula, and the ascent of the ancient volcano *Snæfellsjökull*, situated at its termination. To save a detour the party took boat from *Reykjavík* to the foot of *Mount Esja*, and proceeded round the shore of the

Digitized by Google

Hvalfjörður via Brautarholt, Saurbær on the south shore, and *Innrtholmur* to *Akrafjall*, the Pre-glacial mountain overlooking *Akranes*. Whereas the first excursion lay over the youngest volcanic formation, whose igneous origin was therefore indisputable, the travellers now found themselves in a country occupied by the older Kainozoic basalts which form the foundation of the whole country. Although the surface features of lava had been effaced, and the basalts themselves were often amygdaloidal, Mackenzie recognised the interbedded tuffs as such, and rightly designated these older basalts as ancient lavas. His ingenious argument to explain the presence of calcite and zeolites in these rocks will be noticed later. The route from *Akrafjall* now lay *via Leirá*, over the *Skardsheidi*, to the head of the *Borgarfjörður*; thence through the swampy *Myra Sysla* into the *Hnappadals Sysla*, and along the northern shore of the *Faxafjörður* to *Snæfellsjökull*. Several recent lava flows were encountered on the way, and their position and extent as mapped by Mackenzie agrees well with Thoroddsen's survey. The return journey to *Reykjavík* was made by the northern coast line of the *Snæfells* peninsula; *Stykkisholmur* and *Snóksdalr* were visited, and the track of the outward journey was picked up at the *Borgarfjörður*. Undoubtedly the most interesting result of the return journey was the discovery of the mountains *Drápuhlidarfjall* and *Baula*, which are built of liparite and pitchstone of older Kainozoic age.

The third excursion included a visit to two already famous localities, *Geysir* and *Hekla*, and the discovery of a third region, the *Torfajökull* district, whose geology is especially interesting, as it affords the only known example of Post-glacial liparite lava flows in Iceland. Leaving *Reykjavík*, the travellers headed for *Þingvellir*, situated on the *Þingvallavatn*, the much described lake which owes its existence to subsidence; in the neighbourhood of *Þingvellir* Mackenzie noted the gaping fissures, especially well developed in Iceland, which he says have been formed "by the sinking of the ground during some of those terrible convulsions which have shaken Iceland to its foundations." Mackenzie gives us a very full description of their appearance and action of the

Digitized by Google

Great Geyser, together with an exact plan of the various springs, and a very feasible explanation of the underground mechanism. Crossing the river *Þjórsá* at *Egilstadir*, the expedition made its way to *Mount Hekla*, where numerous specimens of recent basaltic lavas were collected. At *Næfurholt*, near *Hekla*, Mackenzie learned that in the neighbourhood of the *Torfajökull* a great quantity of "Icelandic agate" could be found, and overjoyed with the news—for obsidian was a rock which for several reasons he especially wished to find in situ—he and his friends undertook the strenuous journey of 20 miles and back in one day. After careful comparison with Thoroddsen's map, it appears certain that Mackenzie discovered the *Dómadalshraun*, the northernmost of the Post-glacial acid streams; this stream was not again noticed until Thoroddsen surveyed the area seventy-nine years later. The return journey to *Reykjavík* was accomplished by the southern route *via Hildarendi*, *Oddi*, and *Eyrarbakki*, and thus the last excursion was brought to a close.

The most valuable result of Mackenzie's visit is the extensive rock collection he made in the course of the several excursions; it comprises some two hundred specimens, which are carefully labelled and described in the Appendix to "Travels in Iceland," and considering the limited and often perverted nomenclature available, these descriptions are usually surprisingly accurate. From the point of view of the petrographer, it is unfortunate that the specimens were not always chosen to represent the freshest and most crystalline facies, but were often selected on account of some interesting surface feature which they displayed. Although the area traversed was only a fraction of the island, the collection is quite representative; it contains examples of the older Kainozoic basalts, usually amygdaloidal, doleritic lavas of Glacial and Pre-glacial age, and recent basaltic lavas; among the tuffs and agglomerates are found specimens of the palagonite bearing rocks, and the thin red inter-basaltic partings; acid types are represented by liparites, pitchstones, and perlites, often showing spherulitic alteration, from some of the acid areas in the older Kainozoic country, and rhyolites, obsidian and pumice from the Post-glacial streams

Digitized by Google

of the *Torfajökull* district; basic intrusives are found as a few "greenstones" and tachylitic veins, and the remainder of the collection consists of deposits from the Geysers. The only important igneous rock types which are wanting are gabbro and granophyre, which have sparse and restricted exposures in the Pre-glacial country.

Of less value now, but of historic interest on account of their bearing on the Hutton-Werner controversy, are many of the observations Mackenzie made, and the arguments he adduced from them. Iceland, we know, is built almost entirely of volcanic products, and this struck Mackenzie at once. He says—"The instance of tuffa excepted, I saw no trace of stratification in Iceland, all the rocks having been subjected to a state of perfect fusion" (page 361). He next observed that these rocks fall into two classes, those which showed by their slaggy or ropy surfaces that they had flowed as surface lavas, and others in which these features were absent, and which frequently contained calcite and zeolites in their vesicles. To show that these were really ancient lavas Mackenzie says—"The internal portions (of lava) are more or less vesicular and possess characters more or less similar to those of basalt, greenstone, &c. A great many varieties of those substances may be matched from streams of lava. So striking, indeed, is the resemblance, that the most skilful mineralogist cannot distinguish the one from the other. The chemical analysis by my much lamented friend, Dr. Kennedy, have proved their perfect similarity in composition; and there now remains no doubt that the materials of which both consist are exactly the same" (page 363).

To explain the presence in these ancient lavas of calcite and zeolites, minerals which he rightly says are "destructible in open fire," Mackenzie refers to the experiments of Sir James Hall, which confirmed the conjecture of Hutton that the dissociation of calcite at high temperatures could be restrained by the applications of suitable pressures. From this Mackenzie infers that the amygdaloids were erupted on the sea-floor at such a depth that the prevailing pressure preserved the calcite intact, and, so sure is he of his explanation, that he straightway designated his amygdaloids as "sub-

Digitized by Google

marine lavas." In this, of course, he is very probably in error. The amygdales are doubtless of secondary origin, being deposited from solution, but this, being an odious Wernerian conception, never occurred to Mackenzie, although he was fully aware, from his study of the composition of mineral waters (page 396) that water charged with carbon dioxide could dissolve calcite, and that under certain conditions even silica might be dissolved in considerable quantities. Although probably at fault, in this case, as to the conditions of eruption, Mackenzie was right in the main issue, namely, that the amygdaloids were really lavas, and this he abundantly proved by specimens from the interbedded tuffs and agglomerates.

Perhaps the most conclusive evidence against Wernerism was the discovery of obsidian and pumice under such conditions as precluded any but an igneous mode of formation. We cannot do better than to quote Mackenzie's own words. "So intimately have Werner and his pupils interwoven the minerals in question with other rocks, that, if their origin shall be proved in any one instance to be volcanic, the whole of Werner's theory, as far, at least, as it concerns unstratified floetz rocks, will be unhinged. The importance of a strict examination of them becomes, therefore, very great, both to the supporters and the antagonists of the Wernerian geognosy" (page 366).

The following extract from Mackenzie's journal describes the *Dómadalshraun* flow:—"Opposite was what both my friends and I took to be a stream of common lava, presenting its usual rude and fantastic appearance. On seeing this we were greatly disappointed as we had been on horseback during ten hours, and had seen neither obsidian nor pumice, excepting detached pieces scattered on the ground. On reaching this supposed stream of lava we were agreeably surprised to find it consist of obsidian, pumice, and slags. Those who have seen a stream of rough lava filling up a valley to the depth of thirty feet will have a just conception of the appearance of what was before us. . . . At some distance from the place where we had ascended to the upper surface of the stream, we observed a separation, as if the

Digitized by Google

matter had divided, while flowing, into two branches. We went to examine the farther branch, as it had an aspect somewhat different from that on which we stood. We found the difference to be owing to a greater quantity of pumice being on the surface; when that was removed, obsidian was found beneath. . . . No doubt can be entertained of heat having affected this mass of obsidian and pumice, in some way or other . . . (and) it is clear from its general aspect, without reference to what has been seen in the Lipari Islands, that what we saw was no other than a stream of lava of a particular species. . . . Pumice generally occurs above obsidian; and I consider it as bearing the same relation to the latter, as the common slags of a stream of lava bear to the body of lava " (page 371).

Thus we see that Mackenzie both laid the foundations for a geological knowledge of Iceland, and collected evidence which made the Wernerian hypothesis finally untenable; and further, to him will we be indebted for any new light which the microscopial and chemical investigation of his collection may throw on the history of the North Atlantic Volcanic Plateau.

IV. Brief Outline of Icelandic Geology.

Since the time of Mackenzie, Iceland has received a great deal more attention, and the list of geological literature is a formidable one. The classic work is Th. Thoroddsen's " Island,"[4] which contains the results of his eighteen years' field work, a geological map of the whole country, and all the previous references. In addition there are many valuable specialised papers dealing with vulcanology, glaciology, tectonics, &c., and H. Pjeturss's excellent sketch in the " Handbuch der Regionalen Geologie."[5] As far as the writer is aware there is no brief synopsis available in English; it is hoped, therefore, that the following condensation from Thoroddsen and Pjeturss will not be unwelcome.

Iceland is essentially a basaltic plateau land of comparatively recent age. Although consisting dominantly of

[4] Erganzungshefte Nr. 152, 153 zu Peterm. Mitth., Gotha 1906.
[5] Heidelberg, 1910.

Digitized by Google

volcanic products, sediments are found which reach a notable thickness; in round numbers Pjeturss suggests 4000 m. for the total thickness of the basalt formation, of which he attributes 1000 m. to the interbedded sediments. Stratigraphical treatment of the country is attended with great difficulties, as no continuous faunal, floral, or petrographic horizon can be found from which a general subdivision might be undertaken. Simultaneous volcanic eruptions of widely differing materials are found mingled with glacial deposits, vulcano-glacial formations, coastal deposits, and subaerial denudation products. All these materials have only very limited extension, and the various facies cannot be correlated on account of the continual volcanic activity. Eruption of lava and loose material, progress of glaciers, earthquakes, and dislocations have followed one another since early Kainozoic time, and hardly was a continuous horizon established but it became the prey of vulcanism and denudation.

Interbedded glacial material, however, although often greatly altered, has not been obliterated, and the traces of the first total glaciation form a continuous horizon from which a subdivision may be made. On this basis Pjeturss makes a first subdivision into "Tertiary" and "Quaternary," but in view of the special needs of the case, and the objection to which these terms are open, it is proposed to use the terms Pre-glacial, Inter-glacial, and Post-glacial, the first corresponding with Pjeturss's "Tertiär," and second with "Altquartär," and the third with "Jungquartär." The following table has been constructed from the data of Pjeturss, and it embodies the more recent view as to the position of the "Palagonitformation" of Thoroddsen and the overlying "Doleritformation." These were given by Thoroddsen late Pre-glacial, and Pre-glacial and Glacial ages respectively, but the discovery by Pjeturss of ground moraines in the "Palagonitformation" demanded an Inter-glacial age for both.[6]

The Pre-glacial Formation.

Igneous.—The foundation of Iceland is a basaltic plateau

[6] H. Pjeturss, The "Glacial Palagonite-formation of Iceland." *Scott. Geogr. Mag.*, 1900.

Digitized by Google

TABLE I.—STRATIGRAPHICAL SUBDIVISION OF ICELAND.

	Igneous.	Sedimentary.	
Post-glacial Formation.	Hot springs, Active volcanoes, Basalt, Soda-trachyte.	Aeolian, Alluvial, Fluvio-glacial, Volcano-fluvio-glacial, Deposits.	Recent.
Inter-glacial Formation.	Ophitic basalt (Doleritformation), Tuff and breccia (Palagonitformation).	Conglomerate, Sandstone, Ground Moraines.	Pleistocene.
Pre-glacial Formation.	Period of Volcanic Rest.	Marine Crag of Tjörnes with molluscan Fauna.	Pliocene.
	Basalt with Tuff partings and intrusive Liparite, Granophyre, Dolerite, Gabbro.	Conglomerate, Sandstone, and Clay with plant remains (Surtarbrand).	Miocene and older.

Digitized by Google

of Kainozoic age, somewhat depressed centrally where it is covered by younger rocks. It is exposed in the eastern fjord country, in the north-west peninsula, and also as numerous inliers in the younger formations; its exposed area is rather less than 2/5 of that of the whole country. The basalt sheets are as a rule darker, thinner, and less regularly jointed than the younger flows, and amygdaloids are of more frequent occurrence. Interbedded with the basalts are found thin layers of tuff and breccia, which are often red, as against the dominant brown colour of the younger tuffs. Of intrusive rocks in the Pre-glacial Formation, liparites are the most conspicuous; textural modifications ranging from granophyre to pitchstone have numerous outcrops, especially in the eastern area. Basic intrusives are found as gabbro in large masses at *Vestrahorn* and *Eystrahorn;* as basaltic sills at the *Seydisfjörður;* as coarse dolerite on the eastern side of *Esja;* and as numerous dykes which are found principally at the edges of the sunken areas. About the seats of eruption of the Pre-glacial basalts little is known.

Sedimentary.—In both the eastern and north-western areas are found interbasaltic lignite-bearing sediments (surtarbrandur), sandstones, and conglomerates, which may reach a thickness of 100 m. The contained plant remains do probably not, as Thoroddsen thought, form a single horizon; their age varies from lower Miocene to upper Miocene, and the fact that the only known surtarbrand plants of the eastern country are found at *Holmatindur*, at a height of 700 m. above sea-level, indicates that the oldest basalts may be of Eocene age (Pjetursson).

In the younger division of the Pre-glacial formation is found a sedimentary deposit of great importance. The western side of the *Tjörnes* peninsula in North Iceland consists of marine Pliocene sediments which reach a thickness of 400 m., by far the greatest sedimentary deposit in Iceland. The lowest and most southerly subdivision is especially rich in *Mytilus;* then follows a considerable thickness of highly fossiliferous sandstone with four or five lignite beds; above, this sandstone continues fossiliferous, but without lignite; above this are found brown conglomerates forming

Digitized by Google

an overhanging cliff 70 m. high; these conglomerates are poor in shells, but carry calcified and silicified tree trunks and branches; capping the sediments is found a Pleistocene basaltic flow. The molluscan fauna of *Tjörnes* appears to correspond with that of the Red Crag, but the material has not been investigated fully enough to ascertain its exact position in the Pliocene.

The Inter-glacial Formation.

Igneous.—Under this heading fall all those basalts which contain interbedded glacial material, metamorphosed sometimes almost beyond recognition, the whole of the truly volcanic part of the "Palagonitformation," and the striated ophitic basalts which were classed as the "Doleritformation" by the earlier writers. The Inter-glacial formation occupies the major portion of the surface of Iceland, and reaches a thickness of 800 m. The basalt sheets are, as a rule, lighter coloured, coarser grained, and thicker than the older basalts, and amygdaloids are less frequently found. Columnar structure is often well developed, the finest column ranges belonging almost without exception to this formation. In later Glacial times volcanic activity evinced a marked change, loose material being the dominant product, and lava flows becoming relatively unimportant. The rows of tuff mountains found in the *Gullbringu Sysla*, in the sunk land stretching north from the *Vatnajökull* to the sea, and elsewhere are the ruins of Glacial volcanoes. Towards the close of this period lava again became the dominant product, as is seen from the widespread occurrence of the striated ophitic basalts. These rocks, although thoroughly basic in composition, are light grey in colour due to their vesicularity, and reveal microscopically exceptionally fine ophitic relations between felspar and pyroxene.

Sedimentary.—Intercalated with the Glacial basalts are found glacial, fluvio-glacial, fluviatile, lacustrine, and marine fossiliferous sediments. These have suffered more or less contact metamorphism, being frequently burnt red where they touch the basalts. By far the greater bulk of the Icelandic ground moraines is interbasaltic; they are

Digitized by Google

compact, often brown coloured rocks which were interpreted up to 1900 as palagonite-breccia. Suffice it to indicate the sequence in one typical locality. At *Búlandshöfdi*, on the north side of the *Snæfells* peninsula, are found resting on Pre-glacial basalt, moraine, conglomerate, sandstone, conglomerate, basalt, moraine, sandy clay, conglomerate, and finally basalt and breccia.

In all the sediments reach a thickness of 50 m., and of the 22 molluscan species found so far, 20 are Arctic, such as are found on the coasts of Spitzbergen at a depth of 30 m.[7]

The Post-glacial Formation.

Igneous.—According to Thoroddsen, 130 Post-glacial volcanoes are known; high mountains of the Vesuvius type are rare, flat-domed volcanoes (*Dyngjá*) are somewhat commoner, and rows of comparatively small tuff and breccia cones are most frequent. Fissures are also not uncommon, from which considerable lava masses have been erupted without notable cone formation.

The distribution of the Post-glacial volcanoes is given by Thoroddsen as follows:—

Locality.	Number of volcanoes.	Area of lava. sq. km.
Snæfellsnes,	17	234
Highlands of *Hofsjökull* and *Langjökull*,	9	1034
Reykjanes and adjoining district,	28	1529
Hekla district,	10	523
Veiðivötn,	6	1550
Myrdalsjökull,	2	no lava
Vestur-Skftafellssysla, (Here are the fissures of *Eldgjá* and *Laki*).	4	1368
Vatnajökull,	unknown	
Ódáðahraun,	23	2684
Mývatnsveit,	19	367
Reykjaheidi,	7	730

[7] H. Pjetursss, Om Forekomsten af skalförende i Skurstensler Bulandshöfdi. Med Bemærkninger om Molluskerne af Ad. S. Jensen. Oversigt over det Kgl. Danske Videnskab. Selskabs Forhandlinger. Kopenhagen 1904.

Digitized by Google

Hekla has had the greatest number of eruptions in historic times, namely 20, after which comes *Katla* with 13 eruptions, the last in 1860.

Basaltic lava has been the principal product in Post-glacial times, but one area is known, the *Torfajökull* district, in which soda-trachyte and obsidian have been erupted. As was mentioned before, this unique occurrence was discovered by Mackenzie in 1810.

Hot springs are numerous in Iceland, both in the lowlands (*Geysir* district, *Reykir* in *Olfus*, *Gröf*), and in the highlands (*Kerlingarfjöll*, *Hveravellir*, *Theistareykir*). Generally they appear to be connected with fracture lines, and to be the after effects of Glacial and Recent vulcanicity. In the *Geysir* country there are about 50 boiling springs and mud pools; after the earthquake of 1896 the somewhat senile *Geysir* was stimulated to great activity, which is, however, now abating.

Sedimentary.—The gravel deposits in front of the Icelandic glaciers are called *Sandr*. These are formed partially by the torrential, gravel, and mud-laden glacial streams, and partly by catastrophes called *Jökulhlaup*. The latter may be due to non-volcanic causes such as the obstruction of sub-glacial water courses, and the bursting of dams, or to the activity of sub-glacial volcanoes. This agency is the cause of the greater *Jökulhlaup*, and when it has been acting, the deposits carry slag and ash. The *Sandur* of the south coast is composed of the *Myrdassandur*, which is chiefly volcano-glacial, and the *Skeidarársandur*, whose origin is principally fluvio-glacial. The extensive ground moraine wildernesses of the interior are also called *Sandr*. Striated blocks appear to be of very rare occurrence in the fluvio-glacial deposits, as the markings do not survive long in the torrential glacial streams.

In the desert interior are found considerable aeolian deposits. These consist partly of wind erosion products, and partly of fine volcanic ash and dust. Hawkes has shown that the thin red interbasaltic tuff partings of the Pre-glacial formation were very probably formed by the trapping of thin sheets of this aeolian deposit by successive lava flows.

Digitized by Google

As these deposits are constantly on the move under the influence of wind, their thickness, when appearing as inter-basaltic partings, cannot be taken as a criterion of the lapse of time between successive flows.[8]

Tectonics.

Iceland has been affected in the highest degree by fractures and dislocations. These have doubtless produced the fiords of the eastern country and the north-west peninsula. The principal direction of the fracture lines in the eastern, southern, and south-western parts of the country is south-west—north-east. In the northern country the north—south direction is dominant, and appears in the young sunk lands south of the bays *Skjálfandi* and *Axarfjörður*; in the north-west the direction north-west—south-east predominates. The fracture lines differ greatly in age. According to Pjeturss the oldest are probably early Kainozoic, and the youngest, which are sometimes gaping fractures (*Icel. gjá*), as are found in the recent sunk land south of the *Axarfjörður* are Post-glacial. The basalt sheets usually dip inland, angles of dip of 8-10° are reached, but more accurate measurements are much required. The crag of *Tjörnes* dips along the coast at 8-10° to the north-west, and in the southern area angles of more than 20° are found.[9]

[8] Leonard Hawkes, "The Building up of the N. Atlantic Tertiary Volcanic Plateau." *Geol. Mag.* (vi.), iii., 1916, pp. 385-395.

[9] E. B. Bailey's "Iceland—A Stepping Stone," *Geol. Mag.*, vi., 1919, pp. 466-477, gives an interesting comparison of Icelandic tectonics with those of Glencoe.

Digitized by Google

No. V. — The Carboniferous Strata below the Top Hosie Limestone in North Ayrshire. By J. E. Richey, M.C., B.A.

Introduction.

The area with which this paper is concerned lies for the most part within the Ordnance Survey one-inch Sh. 22, Scotland, but references are made to adjoining portions of one-inch Shs. 30 and 23, which are situated respectively north and east of Sh. 22. The resurvey of these sheets by the Geological Survey has been in progress for a number of years, and that of Sh. 22, in which the writer has been engaged, has now been completed.

A general account is given of the geology of the older Carboniferous strata up to the top of the Lower Limestone Group. Particularly, attention is paid to an overlap of the limestone-bearing strata that succeed the Calciferous Sandstone lavas. This overlap and unconformity was recognised during the original survey fifty years ago. In more recent years, the detailed stratigraphy of the limestone-bearing strata below the Top Hosie Limestone has been worked out by many investigators from surface information and data supplied by bores. Many of the results obtained have been already published in the Society's *Transactions* and in *Geological Survey Memoirs*. In the present paper use is freely made of these sources of information. The writer has also had the opportunity of visiting districts surveyed by other members of the staff. A statement of his main results has been contributed to the "Summary of Progress for 1923" (*Mem. Geol. Surv.*).

The following groups of strata occur within the area:—

Coal Measures.
Millstone Grit.

Carboniferous Limestone Series.	Upper Limestone Group.
	Limestone-Coal Group.
	Lower Limestone Group.

Digitized by Google

Upper Sediments, with marine limestones.

Unconformity.

Calciferous Sandstone Series.

- Volcanic Group, lavas of various types of basalt, mugearite and trachyte, with beds of ash and agglomerate.
- Cementstone Group, marly calcareous blaes with very numerous bands of non-marine limestone—the cementstones.

Upper Old Red Sandstone, including beds of sandy limestone—cornstones.

Lower Old Red Sandstone, including a volcanic group.

Strata below the Unconformity.

A brief sketch of the disposition and the relations of these older rocks is given below.

The Calciferous Sandstone lavas along the west side of Sh. 22 overlie directly the Upper Old Red Sandstone. They are of great thickness to the north, but thin rapidly southwards towards Ardrossan. Their outcrop in the north extends eastwards to separate the Carboniferous Limestone basin of North Ayrshire from that of Renfrewshire. Northwards of the northwest corner of Sh. 22, in Sh. 30, the Cementstone Group makes its appearance between the base of the lavas and the Upper Old Red Sandstone.

In the south-east part of Sh. 22, near Galston, the main lava outcrop, along its south margin, is faulted against a ridge of Old Red Sandstone, comprising both Upper and Lower subdivisions, which extends from there eastwards into Sh. 23. At two exposures in Burn Anne, near Cessnock Castle (55) and near Hillhouse (56),[1] the Upper Old Red Sandstone of this ridge is seen directly overlain by Carboniferous Limestone strata with no representative, volcanic or sedimentary, of the Calciferous Sandstone Series. The thinning out of the lava group is evidently a sudden one, for just north of the Galston Old Red Sandstone ridge, near Newmilns railway station, about 1¼ miles north of Hillhouse, a recent bore pene-

[1] Numbers 1 to 64 included between brackets in the text refer to localities as indicated on Fig. 2.

Digitized by Google

trated the lavas to a depth of over 500 feet without reaching a base.

There is no section within Sh. 22 showing the relation of the lava group at its full development to the cementstones. Where the latter outcrop, south of the Old Red Sandstone ridge of Galston, the lava group is absent, or else very attenuated. In a bore at East Doura (52), its position is marked by beds of "ash" overlying the Cementstone Group. In another, at Mossbog (54), the cementstones occur alone. That the lavas are later than, at any rate, the main mass of the cementstones seems probable. On the other hand, the absence of the cementstones along the west side of Sh. 22 might, perhaps, be argued as indicating an early overspreading of this district by the lavas: volcanic land, if early in existence there, might be the cause of the non-appearance of the cementstones. But the absence of both lavas and cementstones in the Burn Anne sections near Galston necessitates some other explanation of the localised distribution of the cementstones. It may be considered that either (*a*) the cementstones were laid down conformably to the Upper Old Red Sandstone, and subsequently upheaved and denuded from these districts; or (*b*) a local crustal movement occurred at the close of the Old Red Sandstone period, and resulting land, against which the cementstones overlapped, remained uncovered till the beginning of Carboniferous Limestone times. The first theory appears the more likely, for where the cementstones occur, just south of the Old Red Sandstone ridge of the Galston district, passage beds are found between them and the Upper Old Red Sandstone (1923, A, pp. 78-79).[1] Further, in this district the presence of an unconformity at the top of the Cementstone Group is proved by an overlap of the Lower Limestone Group on to cementstones which cuts out the whole of the Upper Calciferous Sandstone Sediments (see page 217 and Fig. 5).

The Calciferous Sandstone lavas in Sh. 22 were, to a large extent at least, poured out subaerially. Their slaggy tops are frequently traversed by a network of cracks filled with red earth or bole. These tops are also often rotted to a soft,

[1] Dated references refer to bibliography, page 232, Appendix B.

Digitized by Google

lateritic clay, evidently by contemporaneous weathering, for the base of the next succeeding flow, often seen in the field, is perfectly sound and unweathered.

At the close of the volcanic period the accumulation of lava flows must have formed a wide expanse of land, and, to judge by the thickness of rotted lava observed at the top of the group in certain districts (Barrmill, Lochside near Lochwinnoch), the lava plateau stood exposed to subaerial decay for a considerable time. Subsequently the lava-land, and also the pre-existing ridge of Old Red Sandstone, with the cementstone area to the south, subsided below water-level, and were succeeded unconformably by the limestone-bearing strata, with which this account is more especially concerned.

Sequence of the Limestone-bearing Strata below the Top Hosie Limestone in North Ayrshire and its Correlation with that of Renfrewshire.

The lavas are everywhere succeeded by beds of volcanic detritus. This widespread deposit (1911, pp. 13-14) consists in North Ayrshire chiefly of red or chocolate-coloured marls and green conglomerates. Well-rounded pebbles which the latter contain are composed of felsite, often porphyritic, greenish or pink in colour. The practical exclusion from these pebble-beds of fragments, large enough for recognition, of the lavas forming the plateau is a curious circumstance, for land composed of the lavas certainly remained exposed to denudation for a considerable time. The subaerial rotting of the lavas most probably led to their contributing practically only fine material to the beds of detritus, while the source of the felsite pebbles may be sought in bombs derived from eruptions late in the Calciferous Sandstone period (1921, p. 48). Typical exposures of volcanic detritus, including pebble-beds, may be seen in the Dusk Water just west of Auchenskeith (11). Ash-beds and agglomerates from which the felsite pebbles may have been derived are found in situ, interbedded with lava flows, along the eastern margin of Sh. 22. In this area the intermingling of the succeeding sediments (including the Dockra Limestone) with volcanic débris led the writer to

Digitized by Google

consider that the final ash phase of Calciferous Sandstone volcanic activity had continued on into Carboniferous Limestone times (1923, A, p. 80). It is now his opinion, however, that the débris, though often angular and extremely fresh, was derived from pre-existing ash-beds in the vicinity.

The sequence of limestones met with in North Ayrshire is given on Fig. 1, together with correlations already made or here suggested with the Renfrewshire development as described by Mr. R. G. Carruthers (1920, pp. 4-19). Details of the North Ayrshire succession have been already published, in a paper by Mr. R. G. Carruthers and the writer (1914, B), as well as its correlation with Renfrewshire down to the Dockra (Hurlet) Limestone, the base of the Lower Limestone Group thus being drawn in Ayrshire at the base of the Dockra Limestone. Correlation below this horizon was not attempted, as the authors considered that until Dockra (Hurlet) Limestone times the two county areas were separated by a ridge of lava-land. It is now the opinion of the present writer that the two areas were in direct communication at a considerably earlier date. The following reasons may be given:—

(*a*) In Ayrshire the maximum development of the limestone-bearing sediments that succeed the lavas is found along the valley of the Dusk Water (see Fig. 2), south-westwards from Hessilhead (24) and Old Mill, and overlap curtails the sequence to south-east and north-west. At the present day lavas are exposed across the line of the Dusk Water depression for several miles north-eastward of Beith and Hessilhead, but there is no evidence of a north-easterly attenuation of the Dusk Water sediments against these lavas. On the other hand, where the sediments are again exposed in Renfrewshire, they are found to have a maximum development along a line through Limecraigs (38) and Paisley, which continues the trend of the Dusk Water trough.

(*b*) The belt of lavas separating the two county areas is partially broken by two north-easterly extending synclinal valleys, in which limestones outcrop (see index map, Fig. 1). In the more easterly valley, the Lugton-Barrhead gap, the strata below the Dockra (Hurlet) Limestone are absent through overlap. But in the more westerly, the Lochwinnoch-Howwood gap, the Broadstone Limestone occurs near Lochwinnoch, while 3 miles to the north-east, at Howwood, the Hollybush Limestone is known to be present. In the intervening ground a bore put down in an old limestone quarry beside the Risk Burn in 1849 proved some 8 fathoms of

Digitized by Google

sandstone and "shale" below the base of the quarried limestone. The limestone is no longer exposed, but it is *tentatively* correlated with the Dockra or Hurlet. This bore has been taken by Mr. D. Ferguson as evidence of an overlap of the limestone on to the lavas (1923, B, p. 275). The section includes two thin bands of "whinstone," 8 inches and 16 inches thick, which Mr. Ferguson regards as lavas, but which the writer interprets as thin sill intrusions, on account of their extreme thinness. Two of the bands of "shale," 4 feet 7 inches and 1 foot thick, are described as "brown" and "red" respectively, and this coloration certainly points to admixture with volcanic mud. But it affords no clue for determining the distance of the limestone above the volcanic floor. Such coloration might occur at any horizon throughout the Upper Calciferous Sandstone Sediments up to and above the Dockra-Hurlet Limestone. There is thus no direct evidence of a lava barrier in the Lochwinnoch-Howwood gap, and sedimentation *may* have been continuous there, on from at any rate Broadstone (Blackbyre) Limestone times.

(c) Correspondence of the limestones below the Dockra and Hurlet seams in thickness and relative position, as well as the general similarity of the limestones and associated sediments, is so close that their correlation as given on Fig. 1 seems justified. This in itself points to direct continuity of deposition.

With regard to the suggested correlation of limestones just mentioned, it must be remembered that the two county districts, where the full sequence is developed, lie some seven miles apart, and that in this interval the strata in Ayrshire have become reduced to about one-third of their Renfrewshire thickness. Some resemblances in detail may be recognised, however, between the two sequences. The whole Ayrshire sequence below the Dockra Limestone is proved by three adjacent bores at Old Mill, between Barrmill and Lugton, and the beds below the Broadstone, though rarely seen, are well exposed in a railway cutting near Thirdpart farmhouse, half a mile east of Barrmill (1914, B, Plate XXIX., p. 254). The (?) Dikebar Limestone is there, as in the Old Mill bores, overlain by a bed of blaes and rests on a coal seam. A hard pyritous fireclay underlies the coal at Thirdpart. The limestone contains abundant *Rhynchonella*, also encrinites and well-preserved specimens of *Nucula attenuata*. Ganoid fish scales are mingled with the marine fossils. The lamellibranch, *Leiopteria divisa*,

Digitized by Google

that occurs so constantly at the Dikebar horizon in Renfrewshire (1920, p. 10) has not been found. Overlying greyish, greenish, or reddish marls, of very fine grain, correspond to the Dikebar Marls. The (?) Hollybush Limestone is ill-exposed east of Barrmill, but further north, in the Dusk Water above Hessilhead (24), it is better seen. It is there a green marly limestone with dendroid corals. Dendroid corals, and also *Productus giganteus*, are typical of the Renfrewshire Hollybush (1914, A, p. 38). But this mark of distinction is of no value in a comparison with Ayrshire, for these fossils occur there at various horizons, for example, in both the Broadstone and Dockra limestones at Lugton. The probable zonal value of variations of *Productus giganteus* has been recently recognised by Dr. G. W. Lee from collections made by Mr. W. Manson (1923, A, p. 123), and it may be hoped that an extension of their work to North Ayrshire will greatly increase our knowledge. In the Broadstone, brachiopods of small size are a feature, while the Dockra, in such sections where fossils abound, is characterised by large growth forms of brachiopods, and also encrinites. The small brachiopod fauna of the Broadstone is in keeping with descriptions given of the Blackbyre (1914, A, p. 38, and 1920, p. 16). It is of some interest that the large encrinites typical of the Dockra occur also in connection with the Hurlet Limestone near Howwood. The Wee Post, occurring between the Broadstone and Dockra limestones, is a good marine limestone in the Beith-Barrmill district, but locally it dwindles to a mere parting of marine fossils—Langside (26). Eastwards at Lugton (23) and southwards at Auchenskeith (11) it disappears, a fact not due to the basal overlap, for at both localities the underlying Broadstone is present. The Wee Post has been correlated with the Baldernock or White Nodular Limestone of Renfrewshire on account of its position relatively to the Dockra (Hurlet) Limestone. In character, near Beith, it is a dark calmy limestone with abundant encrinites, and consequently unlike the Baldernock of southern Renfrewshire (1920, p. 18). But near to its southerly limit of distribution it assumes some of its Renfrewshire characteristics, for it is a nodular white limestone mingled with marly sediment in the Lugton Water near Auchentiber (20).

Digitized by Google

The special characteristics that mark the Dockra Limestone throughout the greater part of Sh. 22 are well known. Its peculiar uneven top, often pierced by rootlets, is overlain by a thin bed of greenish marl or fireclay, succeeded by a few feet of blaes, followed by Limestone A. This association forms a sure guide to its recognition in the field. Its irregular top certainly denotes a slight unconformity, and evidence for considering that the green marl, or ash (as early workers considered it), was laid down in water unconformably to this irregular rooty limestone top, has been stated by Mr. Robert Craig (1882 and 1885). Near to the centre of the Ayrshire trough of sedimentation, however, in the Gurdie railway cutting, S.W. of Beith, and at Blairmill, S.W. of Auchenmade, the top of the Dockra Limestone is even and uneroded, and is overlain by some 20 or 30 feet of blaes before Limestone A is reached. Sedimentation was evidently continuous here. It is to be noted that neither marl nor fireclay are found, unless perhaps at Gurdie, interbedded in the blaes a few feet below Limestone A. An intermediate condition occurs at Limekilns Plantation, Lochwinnoch (32), where beds were exposed by digging, and in the Hindog Glen, N.W. of Dalry (5). In these sections the Dockra Limestone, with perfectly even top, is succeeded by a thin bed of blaes, followed by the green marl with a band of cement, which is overlain by a few feet of blaes and Limestone A. This sequence is paralleled in Renfrewshire by the compressed sequence found above the Main (Hurlet) Limestone of Thorntonhall (1917, pp. 14-15). There the limestone above the green marl has been determined as the Blackhall, being capped by the Neilston Shell-bed. The comparison with Thorntonhall, suggested to the writer by Mr. R. G. Carruthers, strengthens the correlation already made on other grounds of the Dockra with the Hurlet, and of Limestone A with the Blackhall (1914, B, pp. 260-263).

Another correlation has been proposed by Professor Macnair, namely, the Dockra with the Blackbyre; the cement, associated (at Hindog Glen, &c.) with the overlying green marl, with the Baldernock; and Limestone A with the Hurlet (1914, A, p. 12). Some similarity exists between the sequences met with in Renfrewshire below the Blackhall and Hurlet lime-

Digitized by Google

stones respectively (1917, p. 33). But it is the upper of these two sequences and not the lower, as Professor Macnair has suggested, with which the sequence in Ayrshire between the Dockra and Limestone A must be compared. For, if a correlation is made with the lower Renfrewshire sequence, then, below the Dockra-Blackbyre as correlated by Professor Macnair, there are no less than *four* limestones known in Ayrshire to correspond with only *two* in Renfrewshire, and only *four* limestones above this horizon in Ayrshire to correspond with at least *seven* in Renfrewshire. The Ayrshire sequence is altogether more compressed than that of Renfrewshire; the limestones are of about equal thickness, but intervening strata are reduced by about one-half. Disappearance of limestone positions must be admitted on any comparison of Ayrshire with Renfrewshire. In the correlation suggested by Mr. R. G. Carruthers and the writer, Limestone B corresponds to two limestones in Renfrewshire, namely, the Mid and Main Hosies (see Fig. 1). But Professor Macnair's correlation involves an important decrease in the number of limestones in one part of the Ayrshire sequence, combined with an important increase in another, which *à priori* seems improbable. The correlation of Dockra and Hurlet limestones also allows representatives of the Hurlet Coal and overlying "alum shale" being recognised in Ayrshire in the coal and overlying pyritous blaes found at the base of the Dockra Limestone. The pyritous blaes has been searched without result at Hessilhead for Professor Macnair's "Hurlet fauna," which he has traced in the "alum shale" position in the Central Valley of Scotland as far west as Howwood (1914, A, pp. 14-15 and pp. 38-41), but which he failed to locate in North Ayrshire. At Dr. J. Horne's suggestion, further search is being made at various other localities.[1] Above the Dockra (Hurlet) Limestone, in the Hosie Group, the very persistent Hosie Fireclay of Ayrshire corresponds exactly in position to the widespread Lillie's Coal horizon of Renfrewshire. This correspondence Professor Macnair has not entertained in

[1] Since this paper went to press, a good representation of Professor Macnair's "Hurlet fauna" has been found by Mr. W. Manson at the base of the Dockra Limestone near Dalry, Ayrshire. An account of the discovery will be given in the "Summary of Progress for 1924" (*Mem. Geol. Survey*).

Digitized by Google

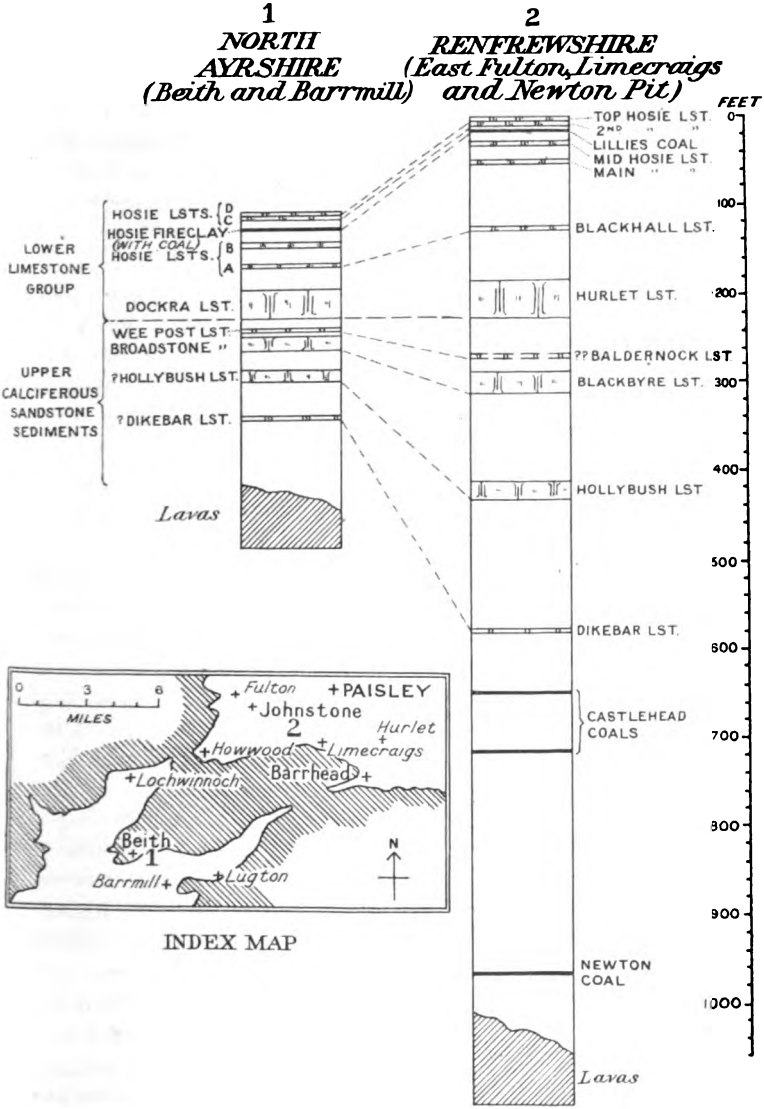


Fig. 1.—Sequences of Limestones below the Top Hosie in North Ayrshire and South Renfrewshire, with correlations.

Digitized by Google

his correlations, for he places Limestone C of Ayrshire, which overlies the Hosie Fireclay, with the Main Hosie of Renfrewshire that occurs below the Lillie's Coal position (1914, A, p. 18). The uppermost Hosie Limestone D of Ayrshire is similar in all respects to the Top Hosie of Renfrewshire. The abundance of the little lamellibranch, *Posidonomya corrugata*, at this position, rarely met with at any other horizon, is a most useful aid to the correlation, and Professor Macnair has proved its stratigraphical value over a wide area in the Central Valley of Scotland.

The identity of the well-known sequence of horizons, Top Hosie Limestone, Johnstone (Dalry) Clayband Ironstone, Johnstone Shell-bed, in the two county areas, is a conclusion which in papers cited has formed the common starting-point for making correlations of lower beds (1914, A, p. 12; 1914, B, pp. 260-261).

Geographical Conditions near the Close of Calciferous Sandstone Times.

i. *After the close of the volcanic period the lava land was in part submerged, and a gulf came into existence which extended north-eastwards across North Ayrshire, and communicated with the Renfrewshire area of deposition. In it the Upper Calciferous Sandstone Sediments were laid down. A land area, at any rate a dozen miles in width, bordered the gulf to the east. To the west, land also existed, but its extent is unknown.*

The above conclusions are based on the known geographical distribution of the limestones below the Dockra (Hurlet) seam, the details of which are given below.

The strata below the Broadstone Limestone, which include two limestones, presumably the Dikebar and Hollybush, are confined to the valley of the Dusk Water, and the two limestones occur at any rate as far south as Monkredding (10), where they were proved in a bore. The Broadstone Limestone is found over a wider area, but it also is confined within definite geographical limits. Its distribution can be traced in considerable detail, as shown on the map, Fig. 2, on which some of

Digitized by Google

the occurrences of its Renfrewshire equivalent, the Blackbyre, are also given. It will be seen that the limestone is found in its normal thick phase over an area extending north-eastwards from Saltcoats, while to west and east it is either absent, or else thin and mingled with marly sediment—evidence of a

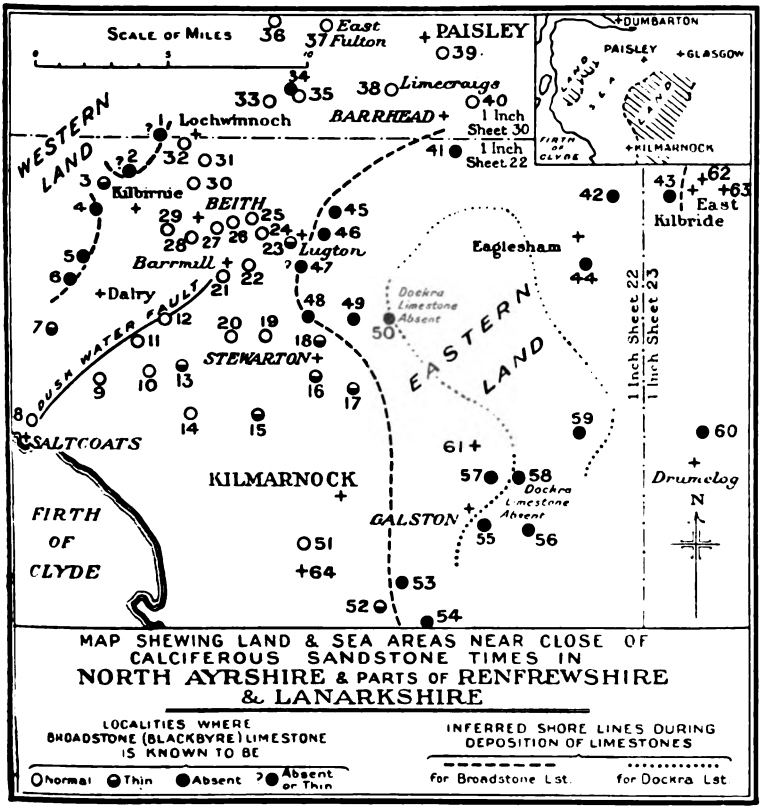


Fig. 2.

Note.—Localities indicated by numbers 1 to 64 are tabled in Appendix A, page 231.

near approach to lava land. Shore lines have been drawn approximately to separate the areas of sea and land. The field evidence leaves in no doubt that these shore-lines bounded extensive land-areas. Reference may be directed to a horizontal section across the North Ayrshire trough of deposition

Digitized by Google

illustrating the overlap of the sediments in proximity to lava land, which is included in a forthcoming Survey memoir (Ayrshire Coalfields, Area I.).

The interpretation of field exposures and bore records calls for some remark. The Broadstone in its normal phase can be recognised without difficulty at the various localities indicated. The beds above it, chiefly marl or fireclay with one or more seams of coal, often including the Wee Post Limestone, distinguish it from the Dockra with its capping of blaes, the only other seam with which it might be confused. At many of the localities where the seam is indicated as thin and marly a slight difficulty of correlation arises. The thin limestone concerned, in each case the only known remaining seam below the Dockra, has been correlated with the Broadstone rather than with the Wee Post, because of the limited distribution of the Wee Post, as already defined (p. 210). At some of the localities where the Broadstone is indicated as absent there is continuous exposure of beds between the lavas or other older rocks up to some horizon above the Broadstone position, and the absence of the Broadstone is demonstrable beyond question (*e.g.*, localities 5, 45). At others, a continuous section down to volcanic detritus is taken as proving the point (*e.g.*, localities 4, 49). In the field, volcanic detritus is found always immediately succeeding the volcanic floor. Coloration of the sediments by admixture with fine volcanic mud to a greater or less degree is, however, a recurring feature of the sequence—up to and above the Dockra (Hurlet) position. Where any uncertainty exists, the locality has been marked with a query.

The eastern land area bordering the gulf was composed to the north of the Calciferous Sandstone lavas. Southwards, near Galston, where the main lava outcrop ends, it consisted of Old Red Sandstone, with an area occupied by cementstones situated still further to the south. Evidence is summarised below.

Fig. 3 illustrates the disappearance of the Broadstone Limestone when followed eastwards against the lava land in the Stewarton neighbourhood. At Auchenmade (12) it is a massively bedded, grey limestone. At a quarry west of Kirkwood (19) it shows signs of

Digitized by Google

deterioration, the limestone being mixed with patches of greenish marl and the seam being much thinner than further west. In the East Burn, west of Causeyhead (18), it is reduced to a 3-foot band of marly limestone, containing dendroid corals and *Productus giganteus*, resting on volcanic detritus and overlain by grey marl. At Gameshill (48) and sections further east (49 and 50), it is absent, and volcanic detritus is directly overlain by the Lower Limestone Group. There is similar evidence of overlap in the Lugton district, to the north of sections just described (see 1914, B., p. 259, and Plate XXIX., sections Barrmill-Lugton).

The evidence for the presence of land composed of Old Red Sandstone will be given later (see p. 221).

The overlap of the Lower Limestone Group on to cementstones is proved by bores and field sections to the south and south-east of Kilmarnock. In a bore near the Hill of Caprington (51), the Broadstone Limestone is identified as a seam of limestone, 12 feet thick, overlying 6 feet of "limy fakes" above 16 fathoms of sandstone, and "red and green fakes" (*presumably* volcanic detritus). South-eastwards, in a bore at East Doura (52), it is represented by a thin band of limestone, containing large producti, which occurs above "ash beds" overlying the cementstones, and which underlies the Dockra Limestone. In a bore at Mossbog (54), and in stream sections at Cairnhill (53), the Dockra Limestone rests almost directly on the cementstones. The latter are immediately overlain by a few feet of sandstone (Cairnhill), which is sometimes pebbly (Mossbog). A similar pebble-bed is found at the unconformable base of the Carboniferous Limestone Series also in Burn Anne sections (55 and 56), which will be again referred to (p. 224).

As shown on Fig. 2, the land extended from near Lugton south-eastwards to the Galston district, and eastwards of this at any rate as far as Drumclog. The land ridge of Broadstone Limestone times was thus at least some 12 miles in width. In Renfrewshire, a lava ridge, long known to occur at Thorntonhall (42), is considered to be the north-eastern extension of the eastern land of Ayrshire. This land-barrier separated the Renfrewshire and Lanarkshire areas of sedimentation up to the time of the Main (Hurlet) Limestone, when a widespread transgression of the sea occurred. It measured perhaps nine miles across, from a point between Maxwelltown (62) and Arrotshole (43) (1917, Plate II.) to the neighbourhood of Barrhead. There is a gap in our knowledge between Thorntonhall (42) and the Auchinback railway cutting S.S.E. of Barrhead (41) (1911, p. 19), but, in the absence of evidence, the continuity of the land is assumed. How far further to the north-

Digitized by Google

east the eastern land may have extended, across what is now the Scottish Central Coalfield, is not known.

Little can be said about the western land bordering the North Ayrshire gulf, except that it evidently formed part of the old volcanic plateau. The available evidence, so far as it goes, proves no more than perhaps a string of islands remaining at the close of the Calciferous Sandstone period, though continuous land must have existed there in Dikebar and Hollybush Limestone times. The only known occurrence in southern Renfrewshire of land to the west of the gulf at the close of the Calciferous period was proved in the Meikle Corseford diamond bore (34), north-east of Howwood (1920, p. 23). It would appear to have been some upstanding portion of the volcanic plateau which remained perhaps as an island. For near-by, to the south-west and south-east, the Hollybush Limestone is known to occur (1920, p. 15).

The Renfrewshire sea-area is in keeping with that of North Ayrshire in that its deepest depression continued north-eastwards the line of the North Ayrshire gulf. To the east, the sediments laid down were restricted by the existence of land. To the west also, though in less striking manner, restriction of sedimentation occurred, for the lava floor comes close up to the Hollybush Limestone near Bridge of Weir (36) (1920, p. 6). The differences between the two county areas are considered due to the subsidence of the land along the site of the gulf taking place at a more rapid rate in Renfrewshire, and so explaining—(*a*) The presence of lower strata in Renfrewshire than are known in Ayrshire, *i.e.*, the beds which include the Castlehead and Newton coals (see Fig. 1); and (*b*) the fact that the amount of sediment laid down in Renfrewshire between any two horizons was at least double the amount deposited in Ayrshire between the same limits. These points will receive further discussion after the history of events has been traced during the period of the Lower Limestone Group (p. 229).

ii. *After the close of the Calciferous Sandstone period, subsidence continued, and so the Dockra (Hurlet) Limestone, the lowest seam in the Lower Limestone Group, is found over a much wider area than the beds below. Land, how-*

Digitized by Google

ever, still existed to the east, perhaps also to the west, for the Dockra Limestone is curtailed and mingled with volcanic débris in its lower portion when traced in both these directions, and to the east it is absent altogether in two districts.

The curtailment of the Dockra Limestone and the admixture of its lower portion with greenish marl, presumably volcanic detritus, are features of nearly all exposures of the seam west of the Kilbirnie-Dalry valley. Only in the Hindog Glen (5) and Baidland Burn (6), westwards of Dalry, is the seam complete, with a coal present at its base. On the east side of the Calciferous Sandstone gulf, the seam is complete at Lugton, but to the north-east (45 and 46) it is reduced to a few feet. Further south, in the Stewarton district, a similar curtailment of thickness occurs at an exposure in the Annick Water, west of Broadland (49). Within a mile E.N.E. of this locality, at Laigh Clunch (50), the seam is absent altogether, and its position is occupied by volcanic detritus and unfossiliferous marly strata. The field evidence on which this conclusion is based requires a more detailed statement. The two sections concerned are therefore figured (Fig. 3), together with sections showing the fuller development further west. In the Annick Water, the section given is exposed in a high bank. The Dockra Limestone is recognisable beyond any doubt, for its uneven top, pierced by rootlets, is overlain by a strip of fireclay which is succeeded by blaes and a limestone of Hosie type. This Hosie Limestone is an encrinital dark band, and its characteristics are of especial importance for reading the Laigh Clunch section. At the latter locality, a similar Hosie Limestone is exposed in a bank section by a stream a short distance above the farmhouse. It is also exposed in a second stream at Laigh Clunch, just west of this farmhouse stream, where the overlying Hosie sequence, as shown in the section figured, can be made out. At both localities the Hosie Limestone is overlain by a fossil bed of distinctive character. This bed consists of a few inches of hard blaes containing in abundance fragmentary remains of a species of *Sanguinolites*. Other fossils are scarce, but *Orthoceras* and *Lingula* were noted. The fossil bed was collected by Mr. W. Manson, of H.M. Geological Survey, and Dr. G. W. Lee considers the prevalent fossil to

Digitized by Google

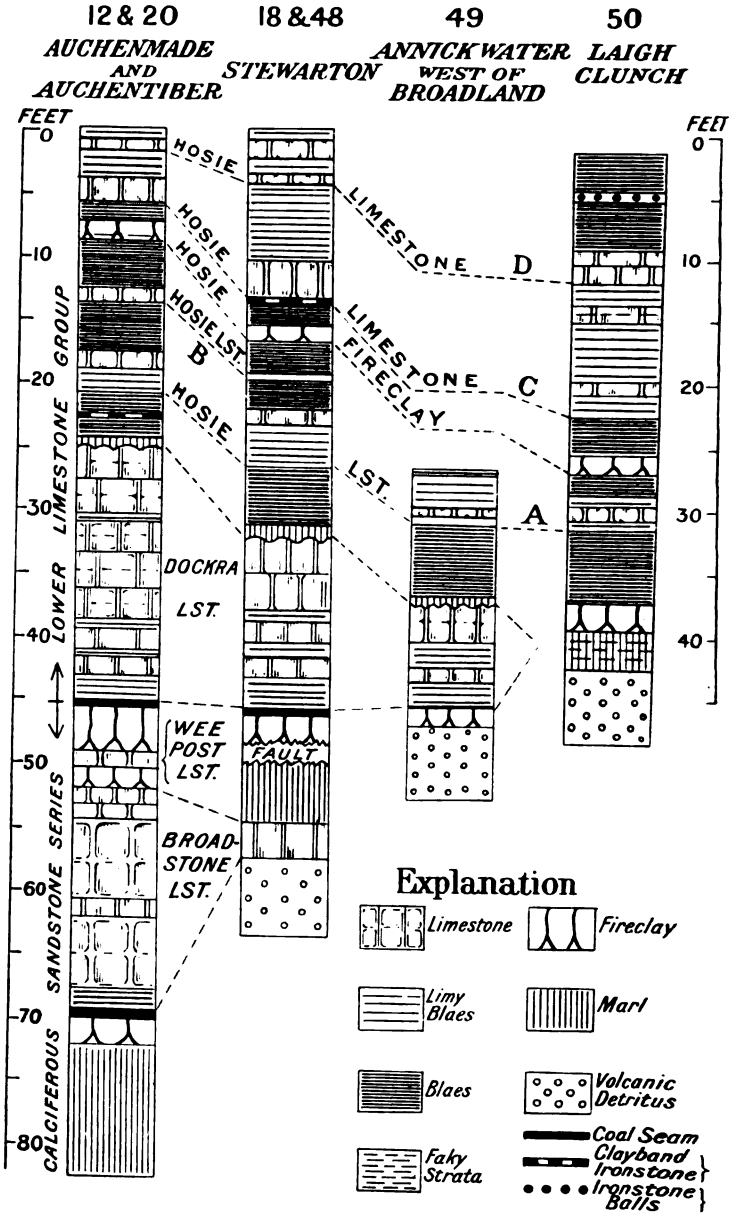


Fig. 3.—Vertical Sections to illustrate overlap of Limestones in the Stewarton district.

Note.—For position of sections as numbered see Map, Fig. 2.

Digitized by Google

be most probably *Sanguinolites variabilis*. Its broken shells at both occurrences rendered specific determination difficult. The identity of the Hosie Limestone of the Annick Water and Laigh Clunch is thus established. Below it, at Laigh Clunch, there occurs a few feet of blaes, then a rooty dark fireclay overlying marly irony beds and good volcanic detritus. No trace whatever of the Dockra Limestone remains, and the considerable amount of volcanic detritus, occurring at the position where it should be, makes it reasonably certain that the limestone has been cut out by the basal overlap. It should be mentioned that the strata at Laigh Clunch are broken by joints and minor faults, but that the writer was convinced that no break of consequence existed in the critical bank section.

South-east of Stewarton lies the Galston district, where the most extreme examples of curtailment of the Lower Limestone Group by overlap have been found. A striking curtailment of Carboniferous strata has been known since the days of the original survey at a splendid cliff exposure adjoining the Burn Anne, near Cessnock Castle (55). Lower Limestones there rest upon the Upper Old Red Sandstone, so that both the cementstone and lava groups are absent. The more detailed study of the limestones of this district, carried out by Mr. E. M. Anderson and the writer, has led to the recognition of the Lower Limestones at Cessnock Castle as the Top Hosie (Limestone D) and Limestone C (see Fig. 4). The Hosie Fireclay is present as a mere strip, full of rootlets, overlying a pebbly layer which marks the base of the Carboniferous system, and penetrating down into the Upper Old Red Sandstone below. The conglomeratic layer contains small pebbles of quartz, dark chert, banded chalcedony, and creamy, compact, cornstone-like limestone. The sandstone underlying it certainly belongs to the Upper Old Red, for it is interbedded with a seam of cornstone, which is characteristic of this subdivision.

The evidence on which the correlation of limestones C and D depends must be stated in some detail. Sections referred to are given in Fig. 4. The Johnstone Shell-bed occurs in the Polbaith Burn (61) as a band of limy blaes very full of small, finely ribbed *Productus* (*P. cf. corrugatus*), and is overlain by blaes

Digitized by Google

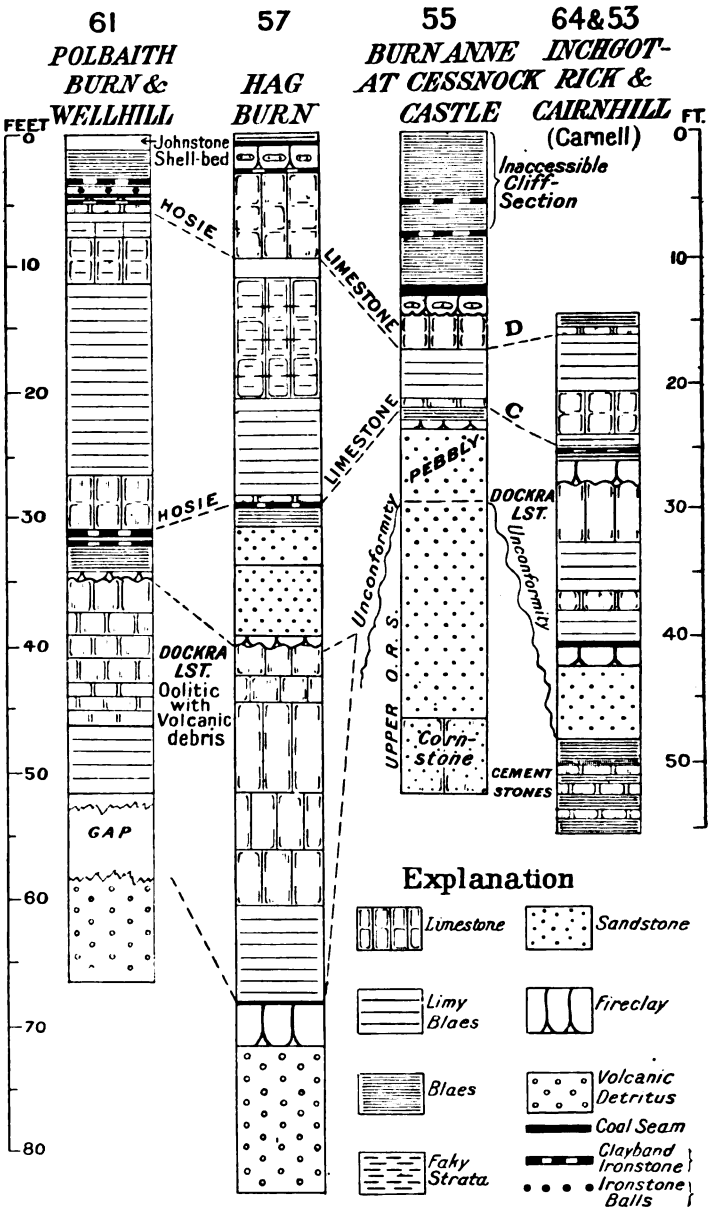


Fig. 4.—Vertical Sections to illustrate overlap of Limestones in the Galston district.

Note.—At locality 55 the Carboniferous includes the Pebbly Sandstone down to the unconformity.

Digitized by Google

and clayband ironstone rich in *Lingula*. It thus resembles exactly the Johnstone Shell-bed known so well further to the north-west in Ayrshire and throughout Renfrewshire. A few feet below it, below blaes with big clayband ironstone balls, the top limestone of the Lower Limestone Group (Limestone D) outcrops. It is a thin cement-like band, red-stained and irony, and contains large corals. An exactly similar band, except that the corals are absent, occurs in a neighbouring quarry near Wellhill. This Wellhill Limestone overlies a thick limy fossiliferous blaes that is matched by blaes occurring in the Polbaith Burn above Limestone C, and its identity with Limestone D is unquestionable. The importance of the Wellhill Limestone lies in the fact that a sequence of beds occurs above it by which Limestone D continues to be marked in the more important sections to the south-east, where, as at Wellhill, the Johnstone Shell-bed is not exposed. This sequence consists of an ironstone band resting on the limestone, succeeded by grey fireclay, containing shreds of ganister-like sandstone and overlain by a seam of coal. The same beds are found also in the Hag Burn (57), where the underlying Limestone D is still cement-like and poor in fossils, but its thickness has increased to the extraordinary amount of over six feet. At Cessnock Castle, above the upper of the two limestones that occur, an exactly similar sequence is found, except that there is no regular band of ironstone capping the limestone, which may be described rather as having an irregular irony top. Its identity with Limestone D of the Hag Burn, Wellhill, and Polbaith Burn is thus established. The seam of coal is succeeded by some 12 feet of blaes with ironstone ribs. In this thickness, in view of the attenuation of strata in this district, the Johnstone Shell-bed might be expected. The upper part of the bed of blaes is, however, out of reach at the top of the cliff-section.

iii. *The eastern land finally disappeared early in Limestone-Coal Group times.*

A still more striking curtailment than that just cited occurs in the Burn Anne near Hillhouse (56), a mile upstream from Cessnock Castle. The Lower Limestone Group is considered

Digitized by Google

to be there entirely cut out by an overlap that brings strata of the Limestone Coal Group unconformably to rest upon the Upper Old Red Sandstone. A conglomeratic sandstone at the base of the Carboniferous strata contains small pebbles of quartz, black chert, and banded chalcedony—as at Cessnock Castle. Above the conglomerate, however, the limestones of Cessnock Castle are absent, and, instead, a series of beds of sandstone, blaes with clayband ironstones and a fireclay and coal are found. A marine bed, with abundant *Productus cf. corrugatus*, occurs near their base. This may be the Johnstone Shell-bed. These beds are often mottled red, a character which Mr. Anderson suggests may be due to the reddening action which characterises the Barren Measures of the Upper Carboniferous, but also sometimes affects the underlying Productive Coal Measures, having extended downwards in this district to a still lower horizon. Their thickness is about 80-90 feet. They are overlain by beds which include limy fossiliferous blaes and a marine limestone. These marine horizons are considered to belong to the Upper and not the Lower Limestone Group for the following reasons:—(*a*) The whole succession has no resemblance to any sequence of Lower Limestone or Upper Calciferous Sandstone sediments in this region; (*b*) on the other hand, there is a correspondence to the sequence of the Limestone Coal and Upper Limestone Groups as known from the nearest bores. Bores at Mossbog (54) and East Doura (52), some three miles to the south-west, both show a very attenuated Limestone Coal Group, and an Upper Limestone sequence similar to that near Hillhouse.

In the bores just referred to, the Lower Limestone Group is present, and in the Mossbog bore it is of special interest that the late Dr. Clough, who examined the cores, found a conglomeratic sandstone just below the base of the Dockra (Hurlet) Limestone resting upon the cementstones. This bed contained the same pebbles as occur in the basal conglomerate of the Burn Anne sections, but Dr. Clough further noted the presence of radiolaria in the black cherts.

Another section where extreme curtailment of beds has been recognised is exposed in the Glen Water and adjoining Mucks Water near Laigh Braidley (59). The occurrence was

Digitized by Google

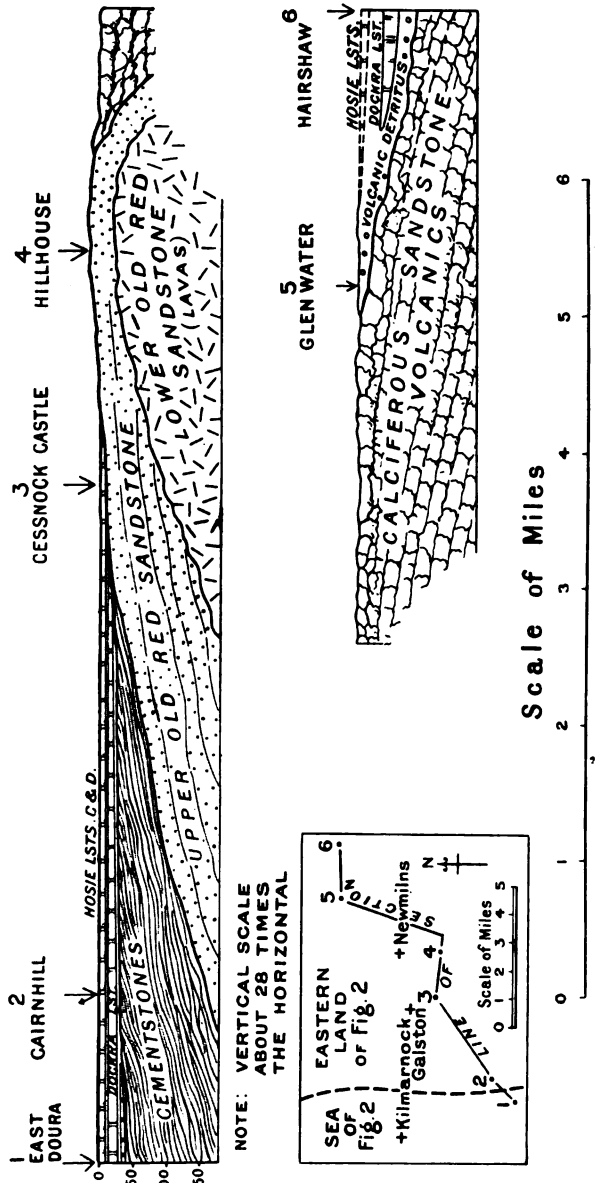


Fig. 5.—Horizontal Section across south portion of Eastern Land of Fig. 2, at close of Lower Limestone times.

Digitized by Google

investigated by Mr. A. G. MacGregor (1924, pp. 92-93). He found that beds of blaes and sandstone with seams of coal, only referable to the Limestone Coal Group, rest there directly upon volcanic detritus overlying Calciferous Sandstone lavas and ashes.

The conclusion is drawn from the examples detailed above that a part of the eastern land remained during the deposition of the Dockra Limestone, and that the land did not finally disappear till after the close of the Lower Limestone period. An attempt to delimit the land of Dockra Limestone times is shown on the map, Fig. 2.

iv. *The Lower Hosie Limestones, A and B, which are present in the north part of Sheet* 22, *are absent to the south-east. This may be due to the slight unconformity at the top of the Dockra Limestone.*

The correlation of the Lower Limestone sequence found in the district where the cementstones occur, to the south of the Old Red Sandstone ridge south-west of Galston, with the type area to the north-west, has led to the above conclusion. This remarkably constant sequence is exposed in a line of quarries that extends eastwards from Inchgotrick (64) for about three miles. Further east, in sections near Cairnhill (Carnell) (53), and in the bores at East Doura (52) and Mossbog (54), the same sequence occurs. It is thus constant for a distance of at any rate six miles. The district was investigated during the resurvey by the late Dr. Clough, and by Messrs. E. B. Bailey and E. M. Anderson, while the task of correlation has fallen to the writer.

The Top Hosie or Limestone D is a thin, irony, cement-like band with a few marine fossils. Its identification depends on the following points:—

(*a*) The band occurs at the visible top of the Lower Limestone Group.

(*b*) In its cement-like character it resembles Limestone D of districts to the north, *e.g.*, Polbaith Burn, Lugton, Calderwood Glen.

(*c*) Close to Inchgotrick farmhouse, in hard blaes underlying it, *Posidonomya corrugata* was found in great abundance.

Digitized by Google

(*d*) The sequence below the shell-bed just mentioned matches well with the sequence associated with Limestone C throughout North Ayrshire. Limy fossiliferous blaes underlies the shell-bed, and caps a fossiliferous dark limestone (Limestone C), which rests on parroty fissile blaes with a reddish clay-band rib containing ganoid fish remains. The blaes overlies a fireclay with rootlets (the Hosie Fireclay), and this rests on the brecciated, uneven top of a light-coloured limestone which is correlated with the Dockra.

The correlation with the Dockra of the limestone last mentioned, which is the lowest seam exposed in the Inchgotrick quarries, is made for the following reasons:—

(*a*) Its brecciated top, often showing concretionary deposition of lime, is a point of resemblance.

(*b*) In its light colour, compact cornstone-like texture, and also considerable thickness, it resembles the Dockra, and not either of the two Lower Hosie Limestones.

(*c*) Where its base is exposed, in a side burn that enters the Cessnock Water near Cairnhill (Carnell), it rests on a seam of coal, and so differs from either of the two Lower Hosie Limestones.

The above correlation leads to the conclusion that the two Lower Hosies, A and B, are absent in this district. These limestones are also considered to be absent in the Polbaith and Hag burns (61 and 57). This curtailment within the Lower Limestone Group is ascribed to the slight unconformity at the top of the Dockra Limestone (p. 211).

Before leaving the Inchgotrick quarries, a reference should be made to the recognition by the late Dr. Clough of horizontal planes of movement that occur along their course, just above the Lower Limestone Group (1915, A). These movement planes Dr. Clough showed to have cut out at any rate 50 feet of strata belonging to the Limestone Coal Group. The great attenuation of the Limestone Coal Group in this district may be partly explained by the occurrence of these horizontal movement planes, as Dr. Clough has pointed out. There can be no doubt, however, that the Carboniferous Limestone Series is really very much reduced, for the Upper Limestone Group, for example, is demonstrably extremely thin, as Mr. E. B. Bailey has indicated (1914, C).

Digitized by Google

The Origin of the North Ayrshire Gulf.

Two theories have been entertained by geologists working in Renfrewshire and the adjoining portions of North Ayrshire to account for the known facts of the overlap. Professor Macnair states that the earlier submergence of the Hurlet district relatively to Ayrshire might be due either to the unequal subsidence of the old lava land, or to its surface irregularity (1914, A, p. 42). The latter view has been considered perhaps the more likely by him, and also by Mr. R. G. Carruthers (1917, p. 9). The writer thinks, however, that the complete Ayrshire evidence, as known, emphasises the importance of the theory of unequal subsidence. This view was entertained by Mr. E. B. Bailey, on account of the attenuation of the Carboniferous Limestone Series southwards of Galston, during his work in that district. The evidence, briefly stated, is as follows: —

(*a*) In northern Ayrshire and southern Renfrewshire, where the Calciferous Sandstone lavas attain a great development, the top group of the local lava sequence, consisting of olivine-rich basalts mainly of Dalmeny Type, outcrop on either side of the sediment-filled gulf, and its continuity beneath the sediments of the gulf is established by intervening exposures. Eastwards of the gulf the group thickens, partly through intercalation with other types of lava. North-westwards, as Mr. E. B. Bailey has shown, it continues uniformly till lost sight of against the Erskine Ferry Fault on the Clyde. South-westwards it dies out near Kilbirnie. Its distribution bears no relation to the course of the Dusk Water and Paisley hollow, and it seems probable that the latter is a later tectonic development.

(*b*) As the lava series is followed south along the west side of the gulf, it diminishes very greatly in thickness, but this diminution is not accompanied by any evidence of an early submersion of this part of the area.

Digitized by Google

(*c*) Towards the southern end of the Eastern Land of Fig. 2 the overlap is particularly marked, in spite of the fact that the volcanic rocks are unrepresented in certain sections. Near Cairnhill (53), for example, the Dockra Limestone rests almost immediately upon the Cementstone Group, and near Cessnock Castle (55) the Upper Hosie Limestones overlie Upper Old Red Sandstone.

(*d*) Unequal subsidence is a feature of Carboniferous Limestone times in Scotland. Recurring cycles of sedimentation often begin with a limestone and end with a seam of coal. These cycles Dr. Peach has considered to indicate periods of rapid crustal depression alternating with longer intervals during which sedimentation went on till, finally, silting up and growth of vegetation with the formation of a coal seam occurred (1915, B). Consequently, the thickness of sediment deposited at any locality during one or more complete cycles may be taken as a measure of the amount of crustal depression involved. This principle receives local illustration in the following instances:—

(i) Along the line of the North Ayrshire gulf, Upper Calciferous sediments, between the lowest (Dikebar) limestone and the Hurlet Coal at the top of the Series, increase in thickness north-eastwards from Monkredding by Barrmill, in Ayrshire, to the Limecraigs district, in Renfrewshire. This variation suggests a crustal depression deepening towards Renfrewshire.

(ii) Mr. Anderson in the "Summary of Progress for 1923" (1924, p. 92), draws attention to a great diminution in thickness of the succeeding Carboniferous Limestone Series south-east of the Dusk Water Fault. This diminution is most marked in the district southwards of Galston, over the site of the Eastern Land of Fig. 2. The conditions of unequal subsidence that gave rise to the North Ayrshire Gulf in late Calciferous Sandstone times closely approximated to those of Carboniferous Limestone times. It may be added that this resemblance finds additional expression in the fact that the Carboniferous Limestone Series, between the Hurlet and Index limestones, gradually increases in a north-east direction along the line of the old gulf, so

Digitized by Google

that near Paisley it is very much thicker than near Saltcoats and Dalry. The increase, indeed, continues further to the north-east by Garscadden and Knightbridge (1920, Plate VIII.) to Kirkintilloch, in the Kilsyth area (1911, p. 34). In the Scottish Central Coalfield there would seem to be the same marked diminution across the trend of the old gulf in a south-easterly direction, as is characteristic of North Ayrshire, for deep bores penetrating the Lanarkshire Coalfield have found the Carboniferous Limestone Series much thinner than at Kilsyth.

The gulf of Calciferous Sandstone times is, therefore, considered to have originated through unequal subsidences which, long subsequently to the disappearance of the Eastern Land, continued to control the amount of sediment deposited over the region. The earlier history of these subsidences is pictured by the writer as follows:—The north-westerly area, continuing along the line of the gulf, subsided more rapidly than the area to the south-east, which included the Eastern Land. The rate of subsidence increased in the north-easterly direction, so explaining the earlier submergence of the Renfrewshire portion of the gulf.

ACKNOWLEDGMENTS.

The writer wishes to acknowledge with many thanks his indebtedness to Mr. E. M. Anderson for his collaboration in the field, in the Galston district, and to Mr. E. B. Bailey for much help received during the progress of the work.

Digitized by Google

APPENDIX A.

TABLE OF LOCALITIES AS NUMBERED ON FIG. 2, PAGE 215.

1. Glenlora Burn.
2. Pundeavon Burn.
3. Paduff Burn.
4. Pitcon Burn.
5. Hindog Glen, Rye Water.
6. Baidland Burn.
7. Roadside E. of Busbie Muir Reservoir.
8. Laigh Dykes, bore.
9. Smithstone, quarry.
10. Monkredding, bore.
11. Auchenskeith, quarry.
12. Auchenmade, quarry.
13. Benthead, bore.
14. Doura, pit.
15. Alton, bore.
16. Wardhead, bore.
17. Low Gainford, burn.
18. East Burn, W. of Causeyhead.
19. W. of Kirkwood, quarry.
20. Lugton Water, Auchentiber.
21. Nettlehirst, quarry.
22. Thirdpart, quarry.
23. Lugton Water, near Lugton.
24. Dusk Water, Hessilhead.
25. Lyonshields, quarry.
26. Langside, quarry.
27. Broadstone, quarries.
28. Roughwood, quarry.
29. Crawfield, quarry.
30. Roebank Glen.
31. Netherhouses, quarry.
32. Limekilns Plantation, quarry.
33. Howwood, bore.
34. Meikle Corseford, bore.
35. Meikle Corseford, burn.
36. Gryffe Water, Bridge of Weir.
37. East Fulton, bore.
38. Limecraigs (Nethercraigs), quarry.
39. Blackhall, railway cutting.
40. Blackbyre, railway cutting.
41. Auchinback, railway cutting.
42. Thorntonhall, quarry.
43. Arrotshole.
44. Enoch Burn.
45. Pollick, railway cutting.
46. Duniflat Burn.
47. Bourrock, railway cutting.
48. Gameshill, railway cutting.
49. Annick Water, W. of Broadland.
50. Laigh Clunch.
51. Hill of Caprington, bore.
52. East Doura, bore.
53. Cairnhill (Carnell), streams.
54. Mossbog, bore.
55. Burn Anne, near Cessnock Castle.
56. Burn Anne, near Hillhouse.
57. Hag Burn.
58. Huggen Craig Burn.
59. Glen Water, near Laigh Braidley.
60. Coldwakning Burn.
61. Polbaith Burn and Wellhill.
62. Maxwelltown.
63. Calderwood Glen.
64. Inchgotrick.

Digitized by Google

APPENDIX B.

BIBLIOGRAPHY.

1882. Craig, R. "On the Fossils of the Upper Series of the Lower Carboniferous Limestones in the Beith and Dalry Districts of North Ayrshire." *Trans. Geol. Soc., Glasgow*, vol. vi., pp. 9, 10.

1885. Craig, R. "Volcanic Disturbance of the Ironstone Measures in the vicinity of Dalry during the Carboniferous Period." *Trans. Geol. Soc., Glasgow*, vol. vii., pp. 234, 235.

1911. "The Geology of the Glasgow District." *Mem. Geol. Survey.*

1914, A. Macnair, P. "The Hurlet Sequence in North Ayrshire." *Trans. Geol. Soc., Glasgow*, vol. xv., pp. 200, 248.

1914, B. Carruthers, R. G., and Richey, J. E. "The Lower Limestones of Renfrewshire and North Ayrshire: a Comparison and Correlation." *Trans. Geol. Soc., Glasgow*, vol. xv., pp. 249-264.

1914, C. Bailey, E. B. "Summary of Progress for 1913." *Mem. Geol. Survey*, p. 64.

1915, A. Clough, C. T. "Summary of Progress for 1914." *Mem. Geol. Survey*, pp. 47, 48.

1915, B. Peach, B. N. "Some Points in the Natural History of the Carboniferous Period in East Scotland." *Proc. Roy. Physical Soc., Edinburgh*, pp. 251, 252.

1917. Carruthers, R. G. "The Economic Geology of the Central Coalfield of Scotland, Area viii." *Mem. Geol. Survey.*

1920. Carruthers, R. G. "The Economic Geology of the Central Coalfield of Scotland, Area iv." *Mem. Geol. Survey.*

1921. Richey, J. E. "Summary of Progress for 1920." *Mem. Geol. Survey*, p. 48.

1923, A. "Summary of Progress for 1922." *Mem. Geol. Survey.*

1923, B. Ferguson, D. "The Hurlet Sequence in Renfrewshire and Dumbartonshire." *Trans. Instit. Mining Engineers*, vol. lxv., pp. 275, 291.

1924. "Summary of Progress for 1923." *Mem. Geol. Survey.*

ILLUSTRATIONS.

Fig. 1.—Sequences of Limestones below the Top Hosie in North Ayrshire and South Renfrewshire, with correlations.

Fig. 2.—Map showing land and sea areas near the close of Calciferous Sandstone times in North Ayrshire and parts of Renfrewshire and Lanarkshire.

Fig. 3.—Vertical Sections to illustrate overlap of Limestones in the Stewarton district.

Fig. 4.—Vertical Sections to illustrate overlap of Limestones in the Galston district.

Fig. 5.—Horizontal Section across south portion of Eastern Land of Fig. 2, at close of Lower Limestone times.

Digitized by Google

No. VI.—Notes on the Geology of the Tarbert District of Loch Fyne.

By W. J. M'Callien, B.Sc., Geology Department, Glasgow University.

The main points in connection with the geology of this district, which includes the mainland to the west of Loch Fyne, from about 7 miles north of Tarbert to a similar distance to the south, have been studied according to the following scheme, which was originally suggested to me by Dr. C. E. Tilley, of the Sedgwick Museum, Cambridge.

(1) The establishment of the southern boundary of the Ardrishaig Group and independent evidence that it is a thrust.

(2) The Limestone problem: or the determination of the relations between the Loch Tay Limestone and the Ashens Limestone, a belt further to the north-west and within the Stonefield Schists, which is looked upon as the Loch Tay Limestone, and mapped as such by Mr. J. B. Hill.

(3) A general study of the metamorphism.

(4) Igneous Geology.

Some points connected with this study, especially of metamorphism, are left for a fuller examination of the peninsula of Kintyre, a district which I find to be as interesting as the classic locality of Cowal; for, besides containing a continuation of the anticlinal structure interpreted on the east side of Loch Fyne by Mr. Clough, a depression at Campbeltown enables us to study the limestones and epidiorites and other rocks as they advance eastward over the underlying Beinn Bheula Grits. South Knapdale also shows a foliation syncline, which I will call the Glenralloch "Syncline," connecting West Loch Tarbert and Loch Fyne, and this part of the area possesses that great development of quartzite known as the Erins Quartzite, and containing the Stronchullin Phyllites which have been examined by Mr. Bailey. Moreover, I find additional interest in the fact that I am unable to agree with the southern boundary of this group of quartzites as it is mapped by the Geological Survey and by Mr. Bailey.

Digitized by Google

The district has already been described in the Memoir on Jura, Knapdale, and North Kintyre, and is included in sheets 28 and 29, but a résumé of the geology will be given.

In the centre of the area stands Tarbert, a picturesque little fishing village nestled among the hills, which owes its origin and development to these three things in order of importance—(1) its proximity to the west coast *via* West Loch Tarbert; (2) the safe anchorage afforded by its harbour; and (3) the presence of the castle usually attributed to Robert the Bruce. Tarbert, as a place name, is extremely common on the west coast, and, according to Gaelic-speaking people, means either a portage or a narrow neck of land. These two derivations, however, are essentially the same, as it is only over narrow isthmuses that boats, implied in the first derivation, would be dragged.

Here at Tarbert, Loch Fyne, the distance between the waters of Loch Fyne to the east and of the Atlantic to the west is less than 1 mile. The highest point between the two is a little over 50 feet, and on the top of the southern valley leading across the isthmus is a flat, half a mile in length, representing the remains of the 50-foot raised beach. Both valleys leading across the isthmus are lined with a rather clayey raised beach alluvium (that to the north is almost entirely boulder clay in its upper part), so that at the time this deposit was being laid down, and when the flat already mentioned was being formed, Kintyre, that part of Argyll to the south of Tarbert, formed one of the numerous islands or chains of islands that then characterised the south-west coast. Even up to the end of the seventeenth century, Kintyre was looked upon as one of the Sudreys, or South Islands.

Picturesque as is Tarbert itself, with the remains of Bruce's Castle standing proudly against the sky, the general scenery of the district is monotonous. The hills represent a continuation of the plain of marine denudation so well known in Arran. The secondary topography which has developed in this table land is dependent upon the nature and strike of the rocks. Thus we have a series of main ridges and valleys running approximately north-east—south-west, parallel with the strike of the schists, and a series of minor valleys which

Digitized by Google

may, or may not, run in a similar direction. Looking west and north-west from the mouth of East Loch Tarbert, we see in the foreground the Beinn Bheula schists and gneisses, towering over the harbour the range of Cnoc a' Bhuic representing the Green Beds, and projecting from the western spur of this range another, flanking the West Loch, and composed of Stonefield Schists. To the north and beyond the latter group is Sliath Ghaoil, giving the general outcrop of the Erins Group, while on its southern side is a ridge of epidiorite.

The main direction of West Loch Tarbert agrees fairly closely with the strike of the rocks, and was originally de-

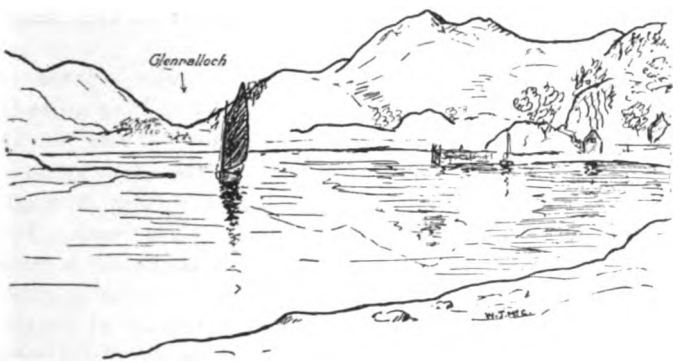


Fig. 6.

pendent on a line of weakness along a strike fault running past Stonefield and along Glenralloch, in a direction parallel and more or less continuous with upper Loch Fyne. This fault I propose to call the "Glenralloch Fault," Fig. 6.

The western shore of Loch Fyne is markedly different from the eastern. The Cowal coast consists of a series of escarpments running out into low, flat points and numerous low islands. Besides the absence of escarpments on the western shore, this coast drops suddenly from heights of from 800 to 500 feet into the sea, and is only very slightly concave from Loch Gilp to the north-eastern coast of Arran.

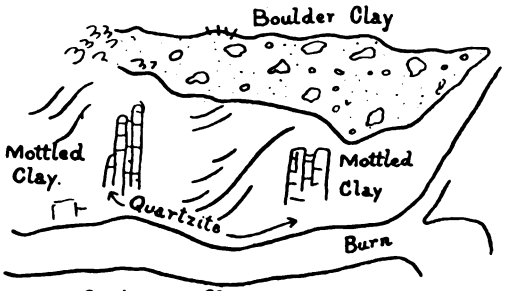
Raised beaches, boulder clay, and peat play a very unimportant part in the modification of the topography.

Digitized by Google

Raised Beaches.—Along the western coast of Loch Fyne raised beaches only occur in the sheltered inlets and ledges between the precipitous spurs of this fiord. The 25-foot beach, for the most part underlain by boulder clay, occurs in all the bays and forms the only suitable sites for such mansion-houses as Erins, Meal Mor, and Stonefield.

On the Atlantic coast the beaches are better preserved, and along West Loch Tarbert we occasionally find the remains of the 100-foot platform. The 50-foot beach forming the summit of the valley separating the two lochs has already been referred to.

Boulder Clay.—The boulder clay of the district is of a bright red colour, and can be examined at places on the road



Burn Section in Clay, N. of Ashens.

Fig. 7.

side north of Tarbert, on the south side of the entrance to the eastern harbour, and at many places in the west loch. The boulders along the shore from the pier to the point separating the inner from the outer harbour are typical of the contents of the till. They are composed of grits and gneisses, with much epidiorite and hornblende schists. Felspar porphyries from further up Loch Fyne are abundant, and there is one large boulder of white porphyritic granite.

In the burn running north-west past Ashens we notice for the first time another type of clay underlying the usual red variety. Though very coarsely bedded, this deposit is remarkably free from boulders and gritty matter, and in this respect resembles a fresh-water lake accumulation. In hand-specimen this clay has a yellowish-red colour, with a white and brown

Digitized by Google

mottled variety. From its colour and appearance under the microscope it approaches the bog iron ore deposits. The variegated facies, however, contains grains of quartz and felspar. A little further down the burn the quartzite beneath the boulder clay has disintegrated with the formation of a pure white material closely resembling China Clay. This shows that the clay is of local origin, the colour being caused by the action of percolating water from the overlying till.

Peat.—Peat is not abundant. Where it does occur, it is for the most part underlain by boulder clay (usually of a yellowish-grey colour), and is of no economic value.

Just south of the old copper mines at Erins is an oblong depression filled with fresh-water sand and gravel (and very subordinate amounts of peat), through which a small burn now cuts its way. This hollow is surrounded to the south, to the west, and to the north by banks of hard rock like quartzite and epidiorite, but to the north-east there is a gap. There is no doubt, then, that this alluvial flat of three-quarter by half a mile represents the remains of a fresh-water loch, the waters of which escaped through the eastern gap.

There are many good, but small, examples of rock basins which are gradually filling up with moss.

Slag, so usually identified with ancient forts, is met with in the most unexpected places on the hillsides. Found in the Beinn Bheula, south of Tarbert, it is more commonly met with in the Loch Tay Limestone region to the north of the last-named group. Though vitrified forts are met with on the Cowal shore right opposite Tarbert, at Dunskeig, about 10 miles south-west of Tarbert, and elsewhere in the surrounding districts, yet no trace of any remains within the actual neighbourhood. About half a century ago, when crofts were common along the slopes of the hills, the crofters always burned their own lime, and in one or two at least of the old kilns there still remains a casing or lining of slag over the interior. In his "Natural History of Selbourne," White says this is "caused by the intense heat from the stones used in building the kiln and from the impurities in the limestone burnt." The remains of the older kilns are now marked by these masses of slag, and though near Aldbea, south of

Digitized by Google

Tarbert, there are no outcrops of limestone, this could easily have been brought by boat from the Stonefield district and burnt at home by the crofters who during the winter were engaged in the fishing industry.

Classification of the Rocks.

Recent and post-Tertiary.

Peat, Marine Alluvium, and Boulder Clay.

Pre-Cambrian Metamorphic Rocks.

Schistose Grits, Greywackes, Quartz Schists, and Quartzite.

Mica Schist and Phyllite.

Green Schists and Crystalline Limestone.

Igneous Rocks.

(1) Foliated: Epidiorite (including Hornblende and Chlorite Schists).

(2) Non-Foliated: Dolerite (and Basalt dykes).

(*a*) East and West.

(*b*) North-west south-east.

:Lamprophyres.

Mineral Resources.—Copper, lead, iron, and barytes, while the only authentic record of gold in the district is that which has been extracted from a small quartz lode near Stronchullin Farm. The gold, unfortunately, is invisible, being in association with copper. Besides lead and copper, zinc, in the form of blende, and galena occur in the lode.

Old copper mines occur at the S.W. base of Meal Mor, about a mile and a half south of Erins. The copper occurs chiefly as copper pyrites in a green-coloured quartzite, which passes in many places into bands composed of chlorite fibres bent into a wavy mass. It is associated with iron pyrites and much calcite. Though copper is abundant, it does not occur in any well-defined lodes, and its out-of-the-way position, together with the scattered nature of its occurrence, has caused its working to be unremunerative.

Sand.—Naturally quartz is the most abundant constituent of the marine deposits, but at Fionfort, a few miles south of

Digitized by Google

Tarbert, a heavy black concentrate occurs on the beach, midway between high and low water marks. Looking at this deposit with a lens, we see abundant perfectly euhedral crystals of magnetite, with other fragments of black iron oxide, quartz, and small pieces of schists, &c. A heavy liquid separation was made and the black material obtained divided into two fragments with a magnet. All the magnetite, however, was not removed by this method. Hæmatite and specular iron are abundant, and some of the grains may be of ilmenite. A most remarkable fact about the non-magnetic fraction was the presence of two garnets, showing that this mineral occurs in the Beinn Bheula Group as far south as the anticlinal region, for the deposit is a concentrate from the rocks in the neighbourhood.

From north to south the Survey has subdivided the metamorphic rocks thus—

Erins Quartzite and Phyllite,
Stonefield Schists,
Loch Tay Limestone,
Glen Sluan Schists,
Green Beds,
} N.W. of Tarbert.

Beinn Bheula Schists and Gneisses—S.E. of Tarbert.

Together the Erins and Beinn Bheula Groups form by far the largest part of the area, the others only occupying a narrow zone between them.

Beinn Bheula Group.—Rocks belonging to this group outcrop along the shore of Loch Fyne from Sgeir Port a' Ghuail to the southern limits of the area. From this Sgeir the boundary runs in a south-westerly direction to the harbour, passes Bruce's Castle, and continues in this direction, except where it has been displaced by small faults. A series of these occurs between the old castle and Alt Tarsuinn. They run right across the strike, and the rocks to the south-west have been displaced to the south. The typical members of the series can be admirably examined on Mealdarroch Point, at the south-eastern entrance to East Loch Tarbert.

The dominant varieties are gneissose grits, granulitic gneisses richer in biotite, and quartz schists. Mica schists are

Digitized by Google

subordinate, but bands rich in chlorite are abundant. Quartz veins are commoner in those varieties of the series which are rich in mica or chlorite than in the more compact and siliceous facies. Here we see bands of very siliceous rocks, with no veins at all, followed by chlorite bands which are riddled with them, and which show beautiful contortions. Subordinate vein materials are felspar, calcite, and iron carbonate, with, at Lagganroag, barytes in abundance. Sometimes masses of dark green chlorite, extremely rich in iron pyrites at times, form the gangue material. Over the district as far south as Laggan, or the Laggan Lochs, tourmaline is common. It occurs in needles, often half an inch in length, and cracked and broken two or three times. When these occur in the coarser rocks of the district they are arranged in any manner with respect to one another and the foliation, but in the finer-grained and more schistose rocks (chlorite varieties) they lie with their longer axes parallel with the foliation planes. Tourmaline is supposed to have been formed in the crystalline schists of the Highlands by the ascension of hot boric vapours through the schists. This would account for its formation along foliation planes, and also for its especial abundance on the margin of a quartz-felspar vein behind Camus na Bantighearna.

That the Beinn Bheula Group is a sedimentary deposit is recognised in the field by the successions of alternate coarse and fine gneisses and schists. In most bands the original clastic nature of the material is visible—the individual grains at times being as large as peas. In some, however, no signs of this structure can be seen. The different powers of resistance of these bands to weathering brings out markedly the stratified appearance.

The coarser gneisses contain pebble-like fragments of quartz of a blue watery colour, with white and pink felspar. The grains, which are lenticular in form, are often $\frac{1}{4}$ to $\frac{1}{2}$ inch long by $\frac{1}{8}$ part of an inch across. They may, or may not, be embedded in sinuous bands of mica, and, as a rule, their outline is quite definite in hand-specimens.

Granulitic gneisses are the finer-grained varieties of the above in which the micas form well-defined folia, and give a

Digitized by Google

more laminated appearance to the rock. These micaceous folia, consisting of the two micas, are thinner than the granulitic mosaic of quartz and felspar.

Other varieties range through the above from bands of massive quartzite to pure chlorite schists. The schists are often rich in magnetite, which is perfectly euhedral and easily attracted by a magnet. Small zones of crush breccia are common, and these are the sources of the many breccia pebbles and boulders one finds among the shingle on the beaches.

All the rocks of this group are much folded, the minor contortions being perfectly brought out and illustrated by the quartz veins with which the rocks are riddled. This is more so the case in the northern half of the area.

Crush Breccia, S. of Mealdarroch Pt.

Fig. 8.

From Tarbert south to Carraig a' Chabaill there is a prevailing dip or " roll " to the north-west, differing much in amount at different places. For 100 yards or so further on the foliation planes are much puckered, but on the whole they are fairly horizontal; then at Fionfort there is a steep inclination to the north-west, the beds becoming horizontal again until, at the southern end of the cliff at Laggan, they dip to the S.E., and continue to dip in this direction to the southern limit of the area.

On the south side of this anticline of foliation the rocks consist of fairly coarse felspathic grits, flaggy quartz schist, mica schist, thin bands resembling the green beds, and abundant black phyllite.

Green Beds.—The group which follows the Beinn Bheula to the north differs from ordinary sediments in composition.

Digitized by Google

In the memoir it is stated that these rocks may have originated as volcanic ash deposited on the sea floor with sands and muds, from which the associated grits and gneisses have been evolved, but that it is more probable that "these bands, in common with the associated schists, were derived from the disintegration of an igneous complex, the more basic portions of which have furnished the materials for this abnormal deposit." Though there is no evidence of volcanic activity, and though the appearance of the rocks does not recall rocks of volcanic origin, I look upon this group, which has such a basic composition, as being the metamorphosed product of contemporaneous igneous rocks.

The Green Beds proper are admirably exposed on the hill to the north of the harbour. Owing to the occurrence of bands

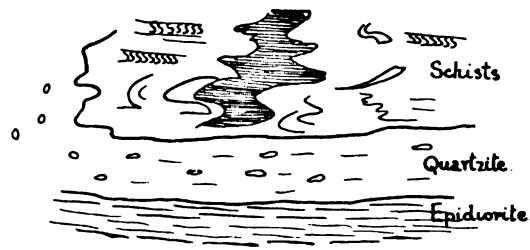


Fig. 9 shows resistance to metamorphism of Epidiorite and Quartzite compared with the Schists. E. of Lochan-da-Cheann-fhinn. Dip is to the right.

of similar rocks in the schistose sediments on either side of the main group and the gradual passage of the main group into these schists, their demarcation is arbitrary. The southern boundary, however, can be drawn much more accurately than the northern one, and runs from Sgeir Port a' Ghuail in a south-south-westerly direction. The northern and more indefinite boundary may be taken somewhat to the south of the Loch Tay Limestone. This band, which we therefore place between the Green Beds and Loch Tay Limestone, contains typical green bed material.

The only difference between the rocks of this group and those of the Beinn Bheula is that they contain more chloritic and epidotic material. That is, they consist of schistose grits and quartz-mica schists (and even quartzite), alternating with the more abundant chloritic and epidotic schists.

Digitized by Google

One unusual variety occurs in the form of two or three thin bands on the top of Cnoc a' Bhuic and on the shore south of Barmore Island. In hand-specimen this rock, which is intercalated with thin bands of quite normal character, is composed of a mass of dark green and silvery mica, studded all over with squares of a blastoporphyritic felspathic mineral. Under the microscope it is seen to be made up of muscovite and green chlorite, with elongated pieces of iron oxide. The remains of garnets are visible in the centre of more or less rounded masses of chlorite, while at other times the shape of the chlorite is all that remains to indicate that it is pseudomorphic after garnet. The slide is exceptionally rich in colourless or iron-poor epidote. The larger crystals are for the most part of plagioclase, showing good cleavages and the

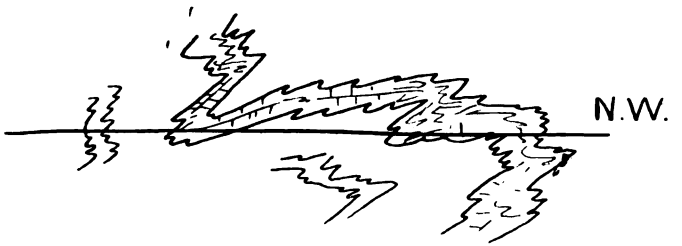


Fig. 10.

remains of multiple twinning. They are quite fresh and rhomboidal in shape, while the foliation "flows" around them. Quartz also occurs as "phenocrysts," but is subordinate in amount. A rock practically similar to this has been found in the Garnetiferous Schists at Glenralloch.

A pebbly variety taken from the southern face of the hill already mentioned consists of quartz and felspar, with laminæ of biotite, and contains oval fragments of a very siliceous rock. These "eyes" are about 2 cm. long by 1 cm. across. Round the margin there is a concentration of biotite. In colour these pebbles are pale green, though in the bands in which they occur there is no hint of epidotic colouring. That they have not wholly escaped the general metamorphism is indicated by the fact that their longer axes are parallel with the foliation. Similar oval structures are recorded from the Green Beds in Cowal.

Digitized by Google

A good section of the rocks of this group occurs on the shore at Port a' Ghuail, where they range from coarse, pebbly types to very fine-grained ones, and, though markedly contorted, they maintain on the whole a steady dip to the north-west. Whereas the Beinn Bheula is extremely contorted, these have resisted the metamorphism better on account of their more massive nature, Figs. 10, 11.

Glen Sluan Schists.—Differing only from the last group in the amount of chlorite and epidote in it, this group is only of secondary importance. The Loch Tay Limestone forms the northern boundary. Apart from the bands of green schists, the rocks are identical with those already described in the Beinn Bheula. A band of epidiorite occurring in this group

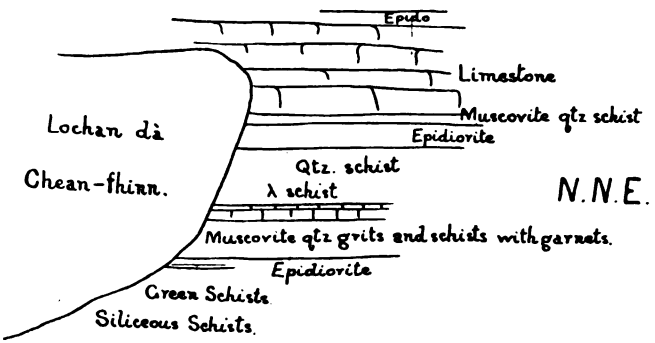


Fig. 11.

is exposed about a quarter of a mile past Carnbuie, in the West Loch.

Loch Tay Limestone.—Outcropping on the shore opposite Barmore Island, the rocks of this group follow a course parallel with the strike of the previous groups. That it is repeated by folding is evident, both from the shore section mentioned above and from the exposures on the top of the hill between Loch Fyne and West Loch Tarbert. The rocks range from a blue wholly crystalline limestone to pale-coloured calcareous (quartz) schists. They show good bedding, along the planes of which, and in irregular patches, muscovite is abundant. Black carbonaceous matter also occurs, and the group as a whole is closely associated with epidiorite. On a weathered surface small grains of quartz are usually visible.

Digitized by Google

On the shore of the South Bay the Loch Tay Limestone is represented by six bands, varying from 30 to 10 feet in width, and separated from one another by epidiorite.

Barmore Island consists of Green Beds to the south, followed by massive epidiorite, and green schists occur again on the northern shore. This " island " has been isolated by a fault running across the narrow isthmus connecting it with the mainland, in a north-westerly or west of north direction, and displacing the rocks in the island to the north. Not only

DIAGRAMMATIC SKETCH OF ALLUVIAL HOLLOW, BARNELLAN.

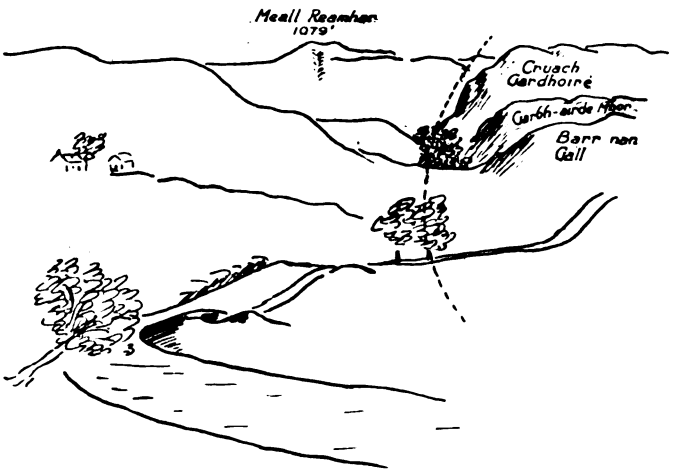


Fig. 12.—This hollow is taken as the boundary of the Stonefield Schists, and is indicated by dotted line.

have they been displaced, but they have been swung round until now their strike is nearly perpendicular to that of the mainland rocks.

Stonefield Schists.—This group follows the Loch Tay Limestone to the north, and is nearly a mile across its strike. To the east soft mica schists, extremely puckered, and containing many garnets, are the predominant rocks. In the western region, however, siliceous varieties predominate. As we proceed north from Glenralloch we find bands of very fine-grained green schists, and coarse felspathic grits with normal quartzites.

Digitized by Google

At Ashens, a band of limestone about 20 feet (or more) in breadth is well developed. It is identical in character with the Loch Tay Limestone, and is represented on the shore of Loch Fyne by small bands. From its field relations, however, it is clear that it is not the Loch Tay Limestone.

Two other bands of limestone are met with in this group. A fairly large and coarsely crystalline one near the southern margin, and a smaller band immediately south of Glenralloch road.

Schistose grits and gneisses (often very coarse) also occur in the group, especially to the north.

Erins Quartzite and Phyllite.—This group of rocks occupies the remaining part of the district, and may be admirably examined in the coast sections. First, to the south, we find siliceous schists and epidiorite with coarser grits, in which blue quartz and felspar lenticles are evident to the naked eye. Alternating with these are small bands of mica schists. Then we find bands of green schists and impure limestone. There is now a gradual diminution in the coarseness of the siliceous rocks, and layers of heavy, grey, leaden phyllite become more frequent. In these bands, usually much crumpled, compared with the massive rocks with which they are associated, it is usual to find crystals which have developed at right angles to the foliation of the band. With a lens these seem to be crystals of biotite.

North of this the quartzite becomes very compact and rich in pyrites, while there is usually a distinct green colour through the whole rock.

Small bands of limestone and calcareous schist are still found, and are well developed to the west of Lochan Liath, towards Kilberry, though they also outcrop in the burn running past Old Ashens. Over the whole area sills of epidiorite are abundant. Though quartzite is the predominant rock of this group, there are two important bands of phyllite, now generally known as the Stronchullin Phyllite, which have caused much controversy as to their stratigraphical importance. They lie somewhat to the S.W. of Stronchullin, between it and Loch Stornoway, and seem to be an integral part of the Erins Group.

Digitized by Google

A slide made from a specimen obtained in a quarry past Barabhalla, in the west loch, shows the rock to be a gneiss composed of quartz, felspar, abundant calcite, and occasional garnets, while in the quarry sections infolds of black phyllite are found.

From Ardtilligan north there is a prevailing dip in a north-west direction, and from about the loch behind Erins to Glenralloch the dip is to the south-east. Between these two localities the rocks are highly inclined now to the north-west, now to the south-east, the contrasted dips usually being separated by rocks in which the foliation and bedding are horizontal. At Meall Mor the bedding planes are distinctly evident, and contortions on a large scale are well seen in the shore sections.

The Southern Boundary of the Ardrishaig Group in South Knapdale.

In the memoir the increasing siliceousness of the Stonefield Schists to the S.W. of the Abhainn nan Gillean is mentioned as being the cause of the difficulty of fixing the boundary between the Erins and Stonefield Divisions, and that, therefore, the present junction shown on the 1-inch published map is of use only as a colourist's boundary. I am unable to agree, not only with that part of the junction mentioned above, but with its continuation right to the shores of Loch Fyne, and I have adopted a new division line between the Ardrishaig Group and the rocks to the south—a line which for the greater part of its course is a natural boundary.

The boundary which I propose to give here is put forward with the realisation that further work in the district may demand another shift, but I claim that it is a truer representation of the junction between two important rock groups than the one at present in use. I give a detailed description of one or two parts enclosed between the existing boundary and this new one (which is further to the N.W.), to show from actual field work that the rocks enclosed therein belong, not to the Erins Quartzite, but to the Stonefield Schists as the Garnetiferous Mica Schist is called in the Tarbert district.

Digitized by Google

The published Survey boundary meets the shore of West Loch Tarbert to the west of the small bay west of Traigh Bhan. The proposed boundary meets it to the west of Torinturk Bay, nearly 2 miles further out along the shore, and the following is a description of the area between these two localities.

Barnellan Quarry—just past the "3-mile-to-Tarbert" stone—consists of quartz-felspar-biotite schist with calcite and garnets, with infolds of phyllitic mica schists and gritty mica schists. Continuing with similar rocks to the south, we meet quartz grits with small opaque felspar grains. Then comes a greenish quartzose gneiss with good strain-slip phyllite. These rocks, with the exception of the very compact quartzose varieties, are highly contorted, the schists having good strain cleavage along which a sericitic mica has developed. Axes of folds pitch on the whole to the S.E. Then comes a muscovite-biotite schist. Barr Uamhach consists of similar variations of micaceous schists. In the second opening south of this hill, and just before reaching the burn, we find a white quartzite with biotite. Across this burn we come to quartz schist and quartzite with biotite and a band of dark colour and of gritty texture, seen under the microscope to be a chlorite-epidote-quartz schist. To the S.W. of the mouth of Barnellan Burn, on the shore, gneissose bands are common among quartz and mica schists. The west shore of Traigh Bhan consists of quartz grits, mica schists, and quartzite charged with abundant biotite. The limestone to the west of the western point of Traigh Bhan is about 5 feet or so wide. S.W. along the shore we have an alternating series of siliceous and micaceous bands similar to those met with to the north. An outcrop N.E. of the small island consists of biotite-quartz schist (or quartzite thickly foliated with biotite) associated with green schists also rich in secondary biotite. The next outcrop, a bit further on, shows a quartz-mica rock not so markedly rich in biotite. Though siliceous rocks are purer than on the shore to the N.E., biotite is still found, and is abundant in some bands. A band of typical green schists occurs on this point, and has been mentioned in the Survey memoir. After passing the wide quartz-dolerite dyke, similar

Digitized by Google

varieties of contorted quartzose and micaceous schists occur, with abundant green schists. Towards Eilean a' Mhadaidh we get mica rocks stained with red iron oxide, and white mica is abundant. On the mainland opposite this island we get quartzite, the foliation planes of which are black with biotite like that met with before. The rocks here are, on the whole, more siliceous than micaceous. At the western side of the bay, S.W. of Eilean a' Mhadaidh and before reaching Torinturk Bay, we get a granular watery quartzite, not unlike the Erins Quartzite, folded and faulted among epidiorites. That this is really a variation of the Stonefield Schists becomes evident on working westward, where the typical quartz-mica schist forms the point at the mouth of Torinturk Burn.

To a person working in the field it is indeed hard to believe that the increasing siliceousness of these schists does not represent a passage to the conditions prevailing during the deposition of the Erins Quartzite. From somewhat similar phenomena to the north-east, although the question of the inclusion of the Erins Quartzite within the Ardrishaig Group is looked upon as settled, I am at present unable to see the justification for this separation from the rocks to the south.

In Torinturk Bay we get quartz grits, calcareous schists, and limestone belonging also, I believe, to the Stonefield Schists. (Small limestone bands have been passed over inside Eilean a' Mhadaidh.) Across the bay are extremely coarse siliceous and felspathic grits, thick bands of fine-grained quartzite, and thin limestones which I take as here representing the southern rocks of the Erins Quartzite division. At the "4-mile-to-Tarbert" stone we begin to notice some of the characteristics of this division—massive bedding and white weathering—though impure gritty biotite rocks also occur. The fine-grained quartzite itself carries biotite. Barr nan Gall, N.W. of the quarry at the 3-mile stone, consists of schists similar to those described to the S.W., with limestone and epidiorite. On the N.W. side of the alluvial hollow here, we get pure and impure quartzites, with biotite and gritty bands. The bedding is typically coarser, and Cruach Glastir is composed of unquestionable fine-grained and pure Erins

Digitized by Google

Quartzite. Towards the N.E., Cnoc Tigh an t' Sluic consists of impure quartzites, and similar rocks occur at the waterfalls in Abhainn na Cuile. Thus the boundary of the Erins Quartzite runs from Glac na Fheadain, to the N.W. of Cruach Gardhoire, along the Abhainn na Cuile as it flows S.W. Then it continues along the hollow between Leacann Bhuidhe and Barr nan Gall, and so to Torinturk Bay. The Abhainn na Cuile itself used to flow along this hollow, but, cutting its way N.W., the Abhainn nan Gillean captured its waters and it was diverted to the S.E., Fig. 12.

A word or two about the north-east of the district. The Survey's boundary meets the coast of Loch Fyne south of Port an Dunain. Here there is no difference in the rocks on either side of the boundary, and I am unable to find any true Erins Quartzite south of Ard nan Ron, nearly a mile to the north. Beginning with the Stonefield Schists at the North Bay, we find quartz-mica schists, quartzites, chlorite schists, and limestones. At Bagh Eich Bhain siliceous schists are abundant among epidiorites. North of the large epidiorite on the north side of Port nan Paisd we meet fairly pure quartzite, with mica and chlorite schists and abundant secondary biotite. The quartzites are only about 1 foot or so thick, and the schists much more extensive. These rocks to the south are garnetiferous, and typical garnetiferous mica schist with abundant garnets occurs on the second small headland north of Ard nan Ron, and nearly a mile north of the Survey's northern boundary of the Garnetiferous Schists. This band is followed by more massive quartzite, which I consider to be the first Erins Quartzite met with from Tarbert north. Unfortunately, this is the last exposure on the shore for a considerable distance. Ard nan Ron itself is mapped as quartzite, and consists of epidiorite and gnarled quartzose mica schists. From this section on the coast the proposed boundary bends to the south for a short distance and then runs in the normal direction to Glac na Fheadain, and, as already stated, from Glac na Fheadain it continues to Torinturk Bay.

Summary.—(1) The schists on both sides of the mapped boundary between the Erins Quartzite and Stonefield Schists are shown to be similar and to belong to the latter group.

Digitized by Google

The dividing line is, therefore, shifted a considerable distance north-west. Also, the southern rocks of the Erins division, according to the proposed boundary, are impure and gritty.

(2) The increasing siliceousness of the Stonefield Schists is taken as indicating a passage to the conditions prevailing during the deposition of the Erins Quartzite. This is in opposition to the interpretation of Mr. E. B. Bailey, for he refers these two groups to different nappes.

Summary of the Stratigraphy.—Mr. E. B. Bailey has assigned the rocks of the south-west Highlands to three great structural divisions, which in descending order are—

(1) Loch Awe Nappe.
(2) Iltay Nappe.
(3) Ballappel Foundation.

The movement and metamorphism have been so closely contemporaneous that "there is no suggestion anywhere of contrasted metaphorphism having been brought into contact as a result of thrusting-thrust movements being supposed to have taken place before the conclusion of the metamorphic period."

Mr. Bailey's study of this part of Scotland has led him to the conclusion that the above Nappes were formed by movements from the north-west, while the formation of the great anticlines and synclines took place after the Nappes as such had come to rest, and "the movements involved in their production seem to have been directed outwards from the Loch Awe Syncline (itself of fan structure), and the Islay Anticline, on its north-west side, has been overthrown towards the north-west, while the Cowal Anticline on the south-east has been overthrown towards the south-east."

To the south of the area we have a continuation of the Cowal Anticline, with axis about Lagganroag. From here to Tarbert the dip of the foliation is in a north-west direction, though varying in amount, until at Tarbert it is almost vertical. From Tarbert to Glenralloch the dips are fairly steep, with a tendency towards the north-west. On the north side of the Glen road the rocks are inclined at not very steep

Digitized by Google

angles towards the south-east. Again they become nearly horizontal, and sometimes dip steeply to the north-west, and sometimes to the south-east, until at Ardtilligan House and to the north of it they dip to the north-west.

Mr. Bailey says the Iltay Nappe, which includes the rocks from Ashens to the southern limit of the area now considered, includes two important folds—the Ben Lui Fold, a syncline closing towards the north-west, and the Carrick Castle Fold, an anticline closing towards the south-east.

In this part of the country the following is the succession in the Iltay Nappe :—

Ben Ledi (or Beinn Bheula) Grits, Mica Schists and Gneisses.
Green Beds.
Pitlochry (or Glen Sluan) Schists and Grits.
Loch Tay Limestone.
Ben Lui Garnetiferous Mica Schist or Stonefield Schists.

The above, being arranged in descending order of age, would indicate that the sequence from Skipness to Ashens is inverted, for the Beinn Bheula structurally underlies the others, Fig. 16.

The Loch Awe Nappe, which follows the Iltay Nappe to the north, has been subdivided thus by Mr. Bailey—

Loch Awe Group.	Loch Avich Slates and Grits. Tayvallich Slates (and Lavas) and Limestone. Crinan Grits and Quartzite. Shira Limestone.
Ardrishaig Group.	Shira Limestone. Ardrishaig Phyllites. Erins, fine-grained (calcareous) Quartzite restricted to Lower Loch Fyne.

Mr. Hill regarded the Erins Quartzite as a local facies of the lower part of the Ardrishaig Group, while Mr. Bailey says it is a separate entity, and that it owes its restricted occurrence to limitation by the thrust at the base of the Loch Awe Nappe. At one time he thought it belonged half to the Ardrishaig Group and half to the Ben Lui Group, but " par-

Digitized by Google

tition is now impossible, since these two groups occur in different Nappes." Mr. Bailey also states that the Loch Awe Nappe travelled into its present position from the north-west. "The evidence relied upon is afforded by the distortion of the underlying rocks, leading, among other results, to the production of the recumbent syncline of Ben Lui."

In the district on the western side of Loch Fyne there is an anticlinal structure, already referred to as being a continuation of the Cowal Anticline, with axis somewhere about Laggan, and a synclinal structure with axis along Glen-

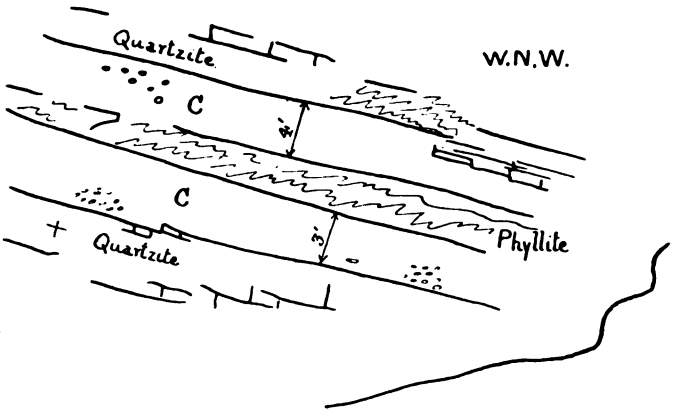


Fig. 13.

ralloch. The Erins Quartzite, on the whole, dips under the Ardrishaig Phyllite in a north-west direction.

Igneous Geology.

(1) *Lamprophyres.*—The most important intrusion of this rock occurs at the roadside on the northern face of Meal Dubh, in the form of a wedge-shaped mass. The narrow end is to the south-east, and the rock dips and increases in width to the north-west, passes under the road, and disappears in the sea. The rocks into which it is intruded consist chiefly of quartzite, with bands of dark-coloured phyllite, belonging to the Erins Group. A quarry was lately started in it for road metal, so that a good section of the fresh rock is revealed,

Digitized by Google

but where the lamprophyre was exposed previously it was much decomposed, and altered to a soft, pale greenish material.

At the margins of the main section the rock is fine-grained, and gradually becomes coarser towards the centre. Under the microscope the marginal variety is seen to be made up of tiny laths of decomposed felspar with calcite, biotite, and some pale green chlorite and magnetite. There is no augite.

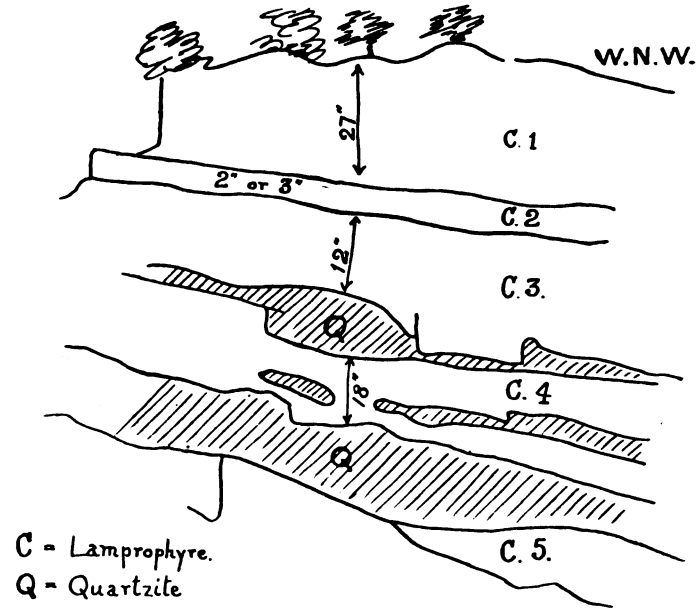


Fig. 14.

but the calcite seems to be pseudomorphic after this mineral.

A slide of the quartzite at the junction shows it to be composed of quartz grains ramified with numerous stringers and irregular patches of biotite, and some other decomposition product and occasional pieces of fine-grained lamprophyre.

This passes down in places into a rock which might almost be described as a schistose lamprophyre, differing only from the last in the marked absence of siliceous material.

Digitized by Google

In the main mass of the lamprophyre accidental xenoliths of black phyllite are met with, and at the upper margin are numerous ocelli of red felspathic material. Further down very coarse cognate xenoliths are extremely common, and vary in size from 2 feet to a few inches across.[1] In other cases the biotite is embedded in a green-coloured mass.

All varieties of this sill are characterised by an abundance of ferro-magnesian minerals—some slides show a predominance of hornblende, others of augite, but the typical member is rich in both hornblende and augite. On the whole, of these two, the hornblende seems to be the most abundant and persistent. It is perfectly euhedral, and of a brown colour. Most slides show many basal sections, which are usually twinned, sometimes with simple, sometimes with multiple, twinning. The larger crystals nearly always contain central cavities which have approximately the shape of the crystal itself, and which are filled with a brown, fibrous mineral, possibly carbonate of iron.

Augite occurs in crystals of two sizes—small pieces crowded among the laths of felspar, and larger ones about the size of the hornblende crystals. In colour it varies from a quite clear and glassy variety to a grey, turbid, and rather decomposed mass. It shows the characteristic cleavages and double refraction.

Biotite is always abundant, and occurs in long, wavy sections which are pleocroic from a very pale greenish-brown to a dark brown. Inclusions of iron oxide are common.

Euhedral crystals of magnetite are scattered about profusely through the whole rocks, while most of the interspaces are filled in with calcite and subordinate quartz. The felspar, which occurs in definite rectangular pieces, is very much decomposed, and of a reddish-brown colour, but, nevertheless, plagioclase can be seen to be more abundant than orthoclase. There are numerous needles of apatite.

One slide of a very coarse hornblende-augite variety is extremely rich in a highly refracting colourless mineral filling in most of the interspaces between the other minerals.

[1] Some of these in hand-specimen are masses of reddish felspar in which are embedded large euhedral plates of biotite.

Digitized by Google

This has a very low double refraction, and is both uniaxial and negative (splendid interference figures having been obtained). Though this is rather an unusual mode of occurrence, it seems that the above agrees more closely with the properties of apatite than with those of any other mineral. Needles of apatite are also abundant in the same slide, and magnetite is exceptionally plentiful.

An examination of the thin end of the sill is most interesting. Here, beginning at the top, we have a band of about three-quarters of a yard in thickness of fairly coarse rock, followed by a thin vein of 2 or 3 inches of very fine-grained material. Then comes a foot of rock which, on the weathered surface, resembles the coarse variety at the top, but which, on breaking, is seen to be fairly fine-grained. No. 4, which encloses a lenticular and a wedge-shaped mass of quartzite, is also fairly coarse, while No. 5, separated from No. 4 by a band of quartzite, is basaltic in appearance, Fig. 14.

The main mass of lamprophyre to the right is made up of two sill-like intrusions separated by a band of black phyllite and white quartzite, studded abundantly with large cubes of iron pyrites. In places the upper sill is well jointed horizontally. Lenticular pieces of quartz occur in the lower band, and the large cognate xenoliths previously referred to are found here, Fig. 13.

Other thin and less interesting sills of a similar rock are met with on the shore just south of the above. They are usually of a reddish colour, with abundant ocelli of red felspar, but sometimes they are quite basaltic in appearance. One sill in the cliff section at the roadside is seen to dip gently to the north, suddenly contract to a few inches in width, and pass steeply downwards across a band of phyllite. Resuming its former dimensions it continues in its downward course as a dyke. This dyke then was the source of the sill which spread out along the feebly resisting phyllite.

A small dyke occurs at the Concrete pier, which, though extremely decomposed, is still seen to resemble the fine-grained lamprophyres. A hand-specimen appears quite red, and a few shiny flakes of mica are all that can be seen in it. Under the microscope this rock is composed of tiny laths of decom-

Digitized by Google

posed felspar, small flakes of biotite, and abundant hæmatite.

(2) *Mealdarroch Point Dyke.*—This is a dark greenish compact dyke outcropping at sea level on Mealdarroch Point, just south of the Concrete pier, and which has been cut away with the formation of a small gulley. The associated metamorphic rocks, in the form of schists and gneisses, have in many places been hardened and darkened in colour.

In hand-specimen the dyke is dark green and aphanitic, with occasional round patches of soft green decomposition products, which are possibly pseudomorphs after olivine.

Under the microscope it is seen to contain phenocrysts or micro-phenocrysts of augite, which are quite colourless. The groundmass appears dark brown in colour, and is composed of a slightly devitrified glass and long laths of felspar, some of which show distinct multiple twinning. This rock, therefore, with its intersertal texture, closely resembles the tholeiites.

Those parts of the adjacent schists which are baked are dark in colour and compact. One specimen taken is a typical quartz schist, composed of folia of quartz and pieces of felspar (showing twinning). Separating these gneissose bands, and scattered through the whole rock, is abundant biotite, in places decomposed and laden with minute cubes of magnetite.

Epidote is also abundant. In shape and optical properties it closely resembles olivine, occurring in perfectly euhedral crystals. These are commonly elongated and traversed by irregular cracks. In colour it varies from colourless to green, the green varieties being distinctly pleocroic.

Refractive index high, and double refraction high. Magnetite is also plentiful in this rock.

Grianain Dyke.—This dyke outcrops on the shore at the Grianain Point, just to the south of Lagganroag, and, being strikingly different from the rocks into which it is intruded, it is so well known to the local fishermen as to receive the name of "Iron Rock." This name must have been given in total ignorance of its composition, and applies to its extraordinary hardness compared with the associated foliated metamorphic rocks.

Digitized by Google

At the sea the dyke has a width of about 50 yards, with fine-grained margins and coarse centre. Augite is distinctly visible in hand-specimen in the coarse varieties. The adjoining schists are much altered—one very dark variety has been converted into a mass of fibrous sericite, with original grains of quartz and much secondary iron oxide. Chlorite is also present. Another red variety of hardened gneiss seems to have suffered an impregnation of felspar, which occurs in rounded or oval fragments up to ¾ inch long. So far this has not been examined microscopically.

The dyke rock itself is a typical quartz dolerite composed of abundant laths of plagioclase with interstitial quartz. Augite, varying from quite clear and colourless to turbid pale green varieties, is plentiful, and in one or two places it is associated with subordinate amounts of chlorite. Hornblende also occurs, but has been much decomposed into a brown fibrous material. There is also much magnetite.

From the shore the dyke runs in a north-west direction, occasionally expanding and contracting in width. It ends off sharply at a small burn running towards Fionfort, and reappears with contracted dimensions about 80 yards further up the burn. Along the bed of the burn there is a shatter zone of red clayey and calcareous material. After this it continues in a westerly, then in a north of westerly direction, with minor displacements and gaps, until it reaches a great shatter zone at Alt Tarsuinn. Here it divides roughly into two, and shows many variations from wide bands of aplite to coarse red felspathic rock.

"The shattered nature of the metamorphic rocks of this area (about a quarter of a mile in length) facilitated their incorporation in the ascending magma."

Under the microscope the red variety is seen to be composed of large decomposed laths of felspar, with interstitial micropegmatite. Augite is not so abundant as usual, and there is plenty of chlorite. Another variety from here approaches frit rock in appearance when seen in thin section. In hand-specimen it is a red, coarse felspathic aggregate, while under the microscope it is seen to be made up of a reddish brown mass of felspar and quartz, with dark brown wavy bands

Digitized by Google

and irregular patches through it. These bands of fused rock are sometimes quite black.

The pale green aplitic rock is similar in mineral composition to the typical augite variety of the parent mass.

A red, compact, and fine-grained vein is seen to pass from the coarse rock to the typical quartz-felspar mosaic through a thin band of similar composition, but showing decided parallel arrangement of the constituents. Then in the centre of the main mass of microcrystalline material is another thin band in which the minerals are arranged in one direction.

Another fine-grained variety is composed of a turbid brown groundmass of quartz and felspar with larger crystals of felspar. Passing the shatter zone, the dyke continues under normal conditions to the coast just past Woodhouse, where it has been quarried for road metal. It reappears on the other side of West Loch Tarbert, below Lochan Liath, and has been traced more or less continuously in an east and west direction, except where at Loch a' Chaorain it follows a N.W. fault line for a short distance, to the opposite shore of Knapdale at Cretshengan Bay. Looking at the Survey map, we see it reappears in Jura, following a similar direction.

No doubt this dyke is also the same as the one which crosses Ardlamont Point and runs right across Bute.

Fionfort Dyke.—Another less interesting dyke occurs slightly to the north of the latter at Fionfort, and is doubtless also an east and west dyke, though it cannot be traced far enough to be sure of the direction; but if, as is most probable, it is a continuation of the one which crosses Ardlamont and Bute north of the Grianain Dyke, then it certainly is. It varies much in width and direction. At the shore it is represented by small tongues about a foot or so in width. This is a shattered area where there are abundant crush breccias and calcite veins, and the dyke itself, which varies from a red to yellow colour, effervesces with hydrochloric acid. In this section it shows good jointing and has indurated the schists in one or two places.

A slide taken from here is seen to be a fine-grained mass of plagioclase laths and calcite. There are also larger porphyritic crystals of plagioclase, and numerous calcite seams pass through the section.

Digitized by Google

A schist from the junction is composed of bands of irregularly shaped pieces of quartz separated by others of muscovite and chlorite, with occasionally magnetite. Calcite and epidote are also present, while tourmaline is abundant. (It is pleocroic, from a dark bluish grey to almost colourless.)

Another slide of the dyke-rock shows a much decomposed mass of brown felspar laths with an especial abundance of iron oxide. Fairly fresh crystals of pale greenish-grey augite also occur.

Carnbuie Dyke.—At the junction of a small dyke outcropping near Carnbuie, on the Tarbert-Campbeltown road, is a band of Frit Rock. This is a glassy grey rock with abundant schlieren of darker material. Under the microscope it is seen to be made up of bands of dark brown and black, containing clear but crushed pieces of quartz. It is, therefore, a typical crush breccia with fusion bands in a quartz schist or gneiss.

Epidiorites.—Epidiorites are distributed over the entire area from the Glen Sluan Schists to the north, and consist of three different types. The first is a more or less fine-grained hornblende schist, identical in many cases with the Green Beds. The second is less basic in appearance, and closely resembles normal diorite in hand-specimen, while the third is medium grained and distinctly ophitic, having suffered very little deformation. Though occurring in separate masses, the fine-grained varieties are also found associated with the coarser. The first coarse band met with in the district runs from Port an Dunain to Abhain an Gillean. In the section of this band mentioned in the south Knapdale memoir we find "large spheroids, about 1 foot in thickness and from 1 to 3 feet in length, consisting of coarsely porphyritic rock, enclosed by thin layers of hornblende schist, the foliation planes of which correspond with the curved surfaces of the spheroids."

One specimen taken from between the road and Lochan Liath is seen to be a compact green schist, with lenticular patches of paler minerals and large plates of dark biotite. The predominant minerals, as seen under the microscope, are green hornblende and colourless highly refracting epidote. The finer-grained folia of colourless minerals between the hornblende laths are composed of quartz and epidote. Iron oxide is abundant, and there is little subordinate chlorite.

Digitized by Google

A coarser variety taken from behind Tuirntuirc Bay, near the old fort, might be termed a hornblende gneiss, though parallel arrangement is not very distinct.

Under the microscope this variety shows large plates of more or less fibrous hornblende, and abundant epidote, with a little quartz. There is a decided lack of magnetite.

Along the road west of Tuirntuirc we find bands of epidiorite among quartz grits and quartzite. At the edge one of these bands shows a gradual passage into dark bronzey biotite schist. That the bands themselves have suffered in the general contortions of the country rock is admirably seen on the roadside near the sixth milestone, where we find a reddish-coloured rock made up of thin contorted bands of siliceous material and dark green chlorite which brings out the contortions beautifully. In thin section we see bands of chlorite in a mosaic of small grains of quartz and felspar.

An ophitic type from the centre of a mass of hornblende schist in Abhain an Gillean Burn shows under the microscope plates of greenish blue hornblende in a groundmass of greyish epidote and colourless interstitial quartz. The hornblende (with a concentration of colour at the margins) shows perfect cleavages and good twinning.

The contact alteration of the enclosing rocks caused by the epidiorite is remarkably well seen in the Loch Tay Limestone at South Bay. At the contact with the igneous rock the limestone has been indurated, recrystallised, and impregnated with bands of a green colour. Under the microscope this rock is seen to be made up of quartz and microcline intimately associated with abundant calcite. Broad bands of chlorite, epidote, and magnetite define a rough foliation.

N.W.-S.E. Dolerite Dykes.—These can be separated into two groups closely related to one another—

(1) Crinanites, and
(2) Olivine Dolerites without analcite.

Under the microscope the crinanites (represented by dykes at Skipness in particular) are beautifully ophitic, and consist of a more or less coarse aggregate of fresh plagioclase, augite, and olivine, with abundant interstitial analcite. Magnetite and

Digitized by Google

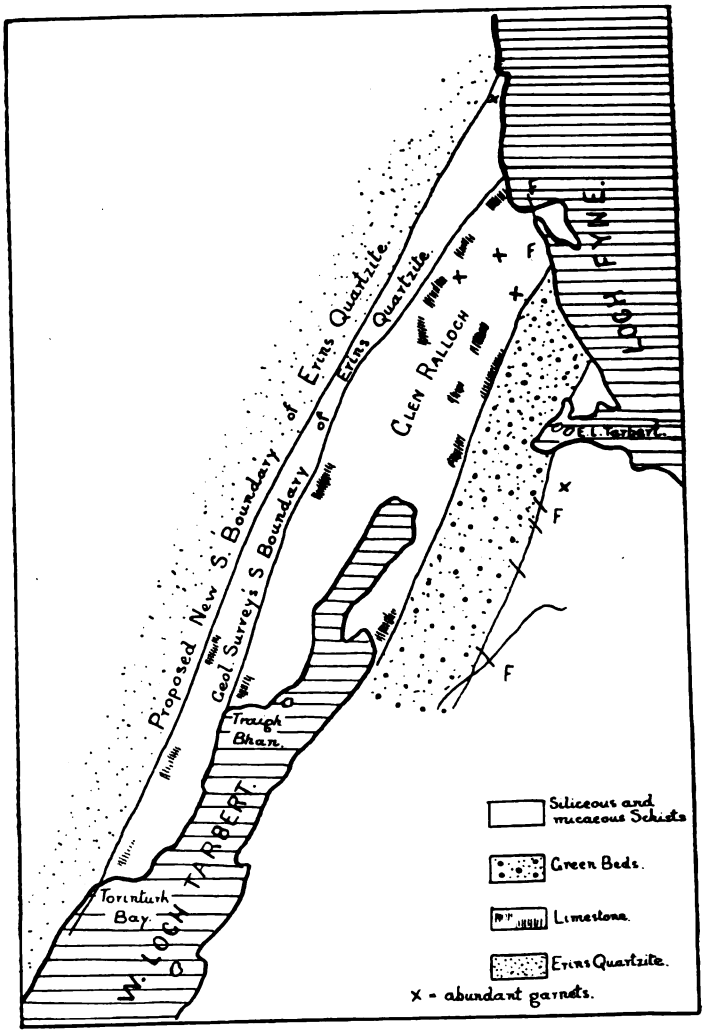


Fig. 13.—Map of the Geology of Tarbert, Loch Fyne, foliated and non-foliated igneous rocks omitted.

Digitized by Google

apatite also occur. The augite is a brown pleocroic variety, while the olivine is often serpentinised to green and yellow.

The dolerites, belonging to the same group but without

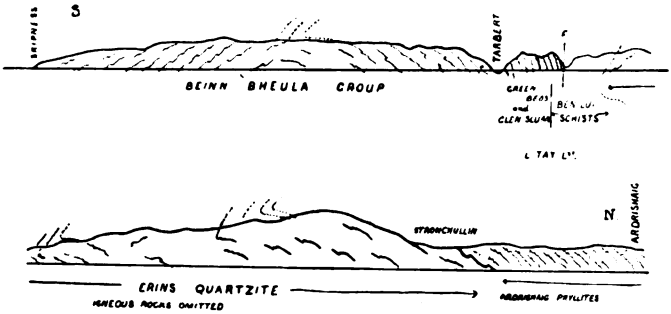


Fig. 16.—Section from Skipness to Ardrislaig.

analcite, consist of similar coarse ophitic aggregates of plagioclase, brown augite, olivine, and serpentine, while zeolites of natrolite are often conspicuous in hand-specimen.

CHIEF WORKS RELATING TO THE GEOLOGY OF THE DISTRICT.

1861. Jamieson, T. F. "On the Structure of the South-West Highlands of Scotland." *Q.J.G.S.*, vol. xvii., p. 133.

1897. Gunn, W., Clough, C. T., and others. "The Geology of Cowal." *Mem. Geol. Survey, Scotland.*

1899. Hill, J. B. "The Progressive Metamorphism of some Dalradian Sediments in the Region of Loch Awe." *Q.J.G.S.*, vol. lv., p. 470.

1910. Gregory, J. W. "Work for Glasgow Geologists—The Problems of the South-Western Highlands." *Trans. Geol. Soc., Glasgow*, vol. xiv., p. 1.

1911. Peach, B. N., Clough, C. T., Bailey, E. B., and others. "The Geology of Knapdale, Jura, and North Kintyre.' (Explanation of Sheet 28.) *Mem. Geol. Survey, Scotland.*

1913. Bailey, E. B. "The Loch Awe Syncline (Argyllshire)." *Q.J.G.S.*, vol. lxix., p. 280.

1922. Bailey, E. B. "The Structure of the South-West Highlands of Scotland." *Q.J.G.S.*, vol. lxxviii., pt. 2, pp. 82-127, and pl. 1.

Digitized by Google

No. VII.—The Permian Breccia of Arran. By B. Hilton Barrett, M.A., B.Sc.

The Breccia which forms the subject of this paper is part of the formation which is mapped by the Geological Survey as Trias. They divide the red sandstones as follows:—

Upper Trias Keuper?	Red and mottled shales or marls with thin beds of white, yellow, or grey sandstone, and occasional thin bands of nodular limestone.
Lower Trias.	False-bedded red sandstones of Brodick and Corrie.
	Conglomerates alternating with sandstones.
	Reddish sandstones with some conglomerates.
	Light-coloured and yellowish sandstones, sometimes red with calcite in cavities.

The stratum with which we have to deal is No. 2, that is, "conglomerate alternating with sandstones." The Survey classification is based on the unconformity between the red sandstones and the Carboniferous below, especially at Corrie; on the lithological similarity to the English Trias; and on the finding of a portion of the upper marls immediately connected with beds of Rhætic Age in a fragment in the Ard Bheinn volcanic agglomerate. Against this, however, Sir Archibald Geikie was disposed to class the standstones as Permian on account of the close similarity to those of Ballochmyle, in Ayrshire. The question of age was finally disposed of by Professor Gregory in his paper, "The Permian and Triassic Rocks of Arran," in the *Transactions* of this Society, vol. xv., Part II. (1913-14). Recently a fresh and confirmatory piece of evidence was discovered by Dr. Tyrrell. This is a bed of volcanic tuff in the bed of the burn in Glen Dubh. Reference to this was made in the programme for the visit of the Geologists' Association to Arran in August, 1923, and fuller reference will be found in the forthcoming proceedings of that Association.

Digitized by Google

Previous references to the breccia are to be found in "The Geology of Arran," by Sir Andrew Ramsay; in Bryce's "Geology of Clydesdale and Arran," and in a paper in the *Transactions* of this Society, "On the Stratified Rocks of the Shore-line from Clauchlands Point to the Cock of Arran," by James Thomson, F.G.S. These are short and mainly descriptive, no attempt being made to examine the pebbles in detail.

The breccia has been studied in four places—(1) From Brodick Pier east and south-east along the Corriegills shore to Clauchlands Point; (2) in the bed of the Machrie Water near the deer-fence about half-a-mile west of the road at Derenenach; (3) in Glen Dubh and the high spur which separates Glen Dubh from Glen Ormidale; (4) at Lochranza.

(1) Of these four, the most important appears to be the first, along the Corriegills shore. Here the breccia is much disturbed by faulting, and is crossed by many dykes. It covers much of the shore, and rises in the cliffs to considerable heights. There is one main fault which brings the false-bedded sandstone, but the dip leads to the reappearance of the breccia further south. On the flanks of the exposure the edges are not seen, as they disappear under the sea, on the one hand, and against the Clauchlands sill on the other. The pebbles vary in size from a diameter of about six inches down to a quarter of an inch. The larger ones are mainly at the northern end, those at the south end being much reduced in size, with an average diameter of about an inch. The dip varies between 15° and 30° to the south-west.

Fully 75 per cent. of the pebbles are vein quartz, and a varying proportion of the remainder are quartzites. These do not lend themselves to an attempt such as this to determine the sources of the materials and the physiography. It must be remembered that the present geographical distribution of land and water gives no assistance. In the available pebbles a large number are unmistakably Highland schists.

Schistose grits.—Pebbles of a fairly coarse schistose grit are common. These are composed of blue quartz grains along with a considerable amount of felspathic material, some of which has decomposed to a yellowish amorphous mineral, possibly kaolin. The "Survey Memoir on Arran" (p. 16) refers

Digitized by Google

to certain beds in the Skipness district of Kintyre as belonging to the upper members of the Ben Ledi Grits, and from these beds the grit pebbles were probably derived. Other pebbles of this group show an almost complete absence of quartz grains; they are much more felspathic in character, most of the felspars being entirely decomposed.

Schists.—Quartz-biotite schists are very common. In several cases the foliation planes are stained red, partly due to the ferric oxide which forms the cementing material of the sandstone matrix It is partly due also to the decomposition of the biotite. This red-stained schist is fairly common in the north end of the Island of Bute, and these beds, no doubt, provided the pebbles.

In other specimens there is little biotite; the rock is a quartz schist. These pebbles show very little staining, and are usually a greenish-grey in colour. They have come almost certainly from the rocks of the southern part of the Highlands.

One pebble of a white schist, soapy to the touch, was found. It is slightly contorted, and is either a sericite schist or a decomposed phyllite. Pebbles of phyllite have also been found.

Slates are also fairly common, but in exceedingly small specimens. They are light-blue in colour. In origin they are possibly from Arran itself, but may have travelled further, as the same slates are found in the Lochranza exposure, and are still small in size.

Some highly contorted slates occur which agree closely with those of Imachar and North Thundergay.

Greywacké.—This rock does not show any marked schistosity. It is dark-green in colour, and similar rocks are found in Bute.

Quartzites.—As already indicated, quartzites are present in large numbers, but it is almost impossible to localise them. One of them would almost certainly be of value, but no source has been found for it. This is a pink vitreous quartzite, whose colour does not seem to be secondary.

Dolomites.—A peculiar rock was found, which is very similar to the dolomite of the Highland Boundary Fault at Innellan and Aberfoyle. It is very much brecciated. It is

Digitized by Google

probably from a more westerly part of the Boundary Fault, which is not seen now.

About halfway between Brodick Pier and Corriegills Point a marked concentration of a cream-coloured dolomite was found. It is remarkable that these pebbles should be confined to the one locality, for they have not been observed in any of the other exposures. Their source is unknown.

Chert.—Specimens of both red and black cherts were found. Sections of both were cut, but there is no sign of organic structure. This is a feature of the Arran cherts ("Survey Memoir, Arran," p. 18). The source may be put as North Glen Sannox.

Sandstones.—A white sandstone which is exactly like the white Carboniferous freestone of Corrie was found.

Red sandstones were also found, and these are in many cases Old Red Sandstone. A calcareous sandstone which, on being split, disclosed a cavity in the centre, is probably from the Lower Carboniferous. Two of these sandstones were cut, and show the particles to be very small and angular. Where the cement is not badly stained with iron, it is calcite. The same sandstone is to be found in the Lochranza exposure.

Cornstone.—Pebbles of this rock exactly similar to those found at present *in situ* on the east shore of Bute south of Kilchattan Bay are present.

Shale.—A red shale, somewhat baked, is probably from the Corrie Carboniferous shales.

Granite.—In referring to the exposure at Lochranza, Ramsay says—"In other cases, with an admixture of quartz, the other pebbles seem principally derived from the underlying schists and slates; but here, as in the Old Red Sandstone, there never occurs a single fragment of granite." This, so far as could be ascertained, is perfectly accurate of Lochranza. On the Corriegills shore, however, it is otherwise. A large concentration of pebbles of a red granite are found; it is again remarkable that, as in the case of the dolomite, these are confined to a fairly small area, although they are also present, as almost the only pebble, in Lamlash Bay. A thin section shows it to be a true granite, composed of orthoclase, quartz, and biotite in small quantity. It is probably an Old Red

Digitized by Google

Sandstone granite. No exposure of this appears to be known in the vicinity at present, and it seems likely that it is now covered by the waters of the Firth of Clyde. This seems the more probable, as it is only on this eastern side they have been found; they are even absent in Glen Dubh.

Agates.—Associated with the granite, and confined almost entirely to the same area, are many agates. Careful search has revealed very little lava with the agates. Some were, however, found, and these appear to be andesites from the slides. These andesites may be derived pebbles from the Old Red Sandstone from the north. At the same time, the association with the agates suggests the possibility of their being derived from an extension of the volcanic rocks now seen at Fairlie. That area is also now under the waters of the firth.

Felsite.—Typical Old Red Sandstone felsites were found, which may be derived pebbles from that formation.

Mudstones.—Mudstones, which come possibly from North Glen Sannox, are also found.

It appears, therefore, that the assemblage of pebbles is almost entirely from the north and north-west of the present island of Arran. No material has come from any far northern source, and may all be described as local.

(2) The second exposure is in the bed of the Machrie Water. The breccia is well seen in the bed of the stream, but no exposures beyond this were examined. Here the pebbles are almost entirely schists and quartz, with some jasper of unknown origin.[1] The finest specimen of Ben Ledi Grit was found in this place, and was fairly common. The dip is downstream at about 10° S.W. Here all the pebbles seem to be from the direction of South Argyllshire.

(3) Glen Dubh. Here the breccia is well exposed in the bed of the stream and in the high spur which separates Glen Dubh from Glen Ormidale. In the latter case the breccia is seen to have a thickness of about 200 feet. Schists, schistose grits, and small pieces of slate are again present, along with quartz. Jasper is again found; while another single specimen

[1] Since this was written jasper pebbles have been reported by Mr. W. J. M'Callien, B.Sc., from the Old Red Sandstone of the Kintyre Peninsula, and the present jasper pebbles are probably from this source.

Digitized by Google

of the cream-coloured schist was present. The dip is about 10° S.E. In this area a very common pebble is a felspar porphyry. The felspars are much decomposed. The presence of hornblende, also decomposed, suggest that it is of Old Red Sandstone age. A probable source is again the Loch Fyne region. In the general characteristics of the assemblage, this exposure closely resembles that on the Corriegills shore.

(4) At Lochranza the exposure is again a shore and cliff section. To call it Lochranza is not strictly accurate, as the point in question is really at the Cock of Arran. The dip is about 20° to the N.W. The exposure is cut off on the one side by the sea, and on the other it is faulted against the Carboniferous and the schists. On the east it comes in above the Carboniferous. This exposure contains the great landslip called the "Scriden." Of this Ramsay says—"The scene here is, if possible, even more magnificent than that at the Fallen Rocks, and, from the extent of the debacle, it is necessary in following the line of coast to climb over the ruins by a rough and winding route, rendering the passage, to unaccustomed feet, both fatiguing and difficult. It is an arduous climb to reach the summit of the hill, but, when reached, it will be seen that the great mass of the strata has been shifted from its original position and slid down the mountain, and, being rent latterly in many places, as the masses were detached from each other, they are now separated by narrow chasms of great depth." It was from this exposure that the derived Carboniferous fossils were obtained by Messrs. Wünsch and Thomson. None were observed on this occasion.

Once again schists were the prevalent pebble, along with the usual quartz. Red sandstones, similar to that already noted at Corriegills, were found, along with Calciferous Sandstones, which effervesce freely with cold acid. Shales of Carboniferous age are fairly common, and red Carboniferous Limestone is also present.[2] Specimens were also obtained of a fine

[2] In his paper Mr. Thomson notes at the Cock of Arran, "chocolate-coloured chloritic shales." One specimen of this was found. Miss Neilson kindly made a blow-pipe analysis of this. The specimen proves to be hæmatite with crystalline chlorite, and is almost certainly of secondary origin. Secondary hæmatite is common and some secondary quartz in crystalline form.

Digitized by Google

crystalline limestone, which is possibly the Loch Tay Limestone drawn from a western part of it. One remarkable point is to be observed here. In a few cases the pebbles are of very large size, much bigger than any observed elsewhere. One measured 14 × 9 × 5 inches, and several others were of about the same order of size. It is true that pebbles of considerable size are to be found at the northern end of the Brodick exposure, but it is highly probable that these have been derived from the Old Red Sandstone conglomerate.

A slight examination of the sandstone matrix was made by means of bromoform separation. The amount of the heavy residue was not determined, but was about 1 per cent. It contained no magnetic particles. The majority of the minerals were garnet, rutile, zircon, and iron ores. The light residue was entirely quartz, felspar, and a little calcite. The grains have a polished appearance, and among the larger particles some were observed to be perfect spheres. In the exposure at Glen Dubh one pebble of quartz had a brilliant polish, and in the others many are observed to be facetted.

It appears from the evidence of the pebbles that the breccia was accumulated by floods of water, and that the sources were all comparatively close at hand. Considering the exposures and the specimens obtained in each, it appears that at least three rivers were involved. As has been shown for the Brodick section, many of the pebbles have their origin in the north end of the island, as it stands at present, and in Bute. To these we have to add the Highland schist pebbles, which are exactly similar to those in the Cock of Arran section. It appears that one river or series of water courses passed southward, depositing material from the Highlands at the Cock of Arran, and the area now only exposing schists, and so on to Brodick. It seems to have been joined by another from Bute, which brought material from the east side of Arran. Finally, the exposures at Machrie Water and Glen Dubh seem to indicate a third source coming from the west. The character of the sand grains and the facetting of certain of the pebbles indicates that these streams were not continuous.

Digitized by Google

No. VIII.—A Contribution to the Petrography of Iceland: Being a Description of the Mackenzie Collection of 1810.

By Martin A. Peacock, B.Sc., L.R.A.M., Carnegie Research Fellow, University of Glasgow.

TABLE OF CONTENTS.

PAGE

I. Introduction, ... 273
The Mackenzie Collection.
Previous Petrographic Papers.
Stratigraphical Subdivision of Iceland adopted.
Basis of Grouping and Method of Description.

II. Basalts from the Pre-glacial Formation, ... 276
Specimens from *Akrafjall*,
Stapi,
Fróðá,
Vestri Skardsheidi,
Egilstadir.
Analyses; Comparison of "Norm" and "Mode."

III. Basalts from the Inter-glacial Formation, . . . 281
Age of the "Doleritformation."
Specimens from *Keflavik*,
Reykjavik.
Hafnarfjörður.
Antipathetic Relationship between Augite and Olivine.
Palagonite-dolerite from *Viðey*.
Analyses; Comparison of "Norm" and "Mode."

IV. Basalts from the Post-glacial Formation, ... 287
Basalts with macroporphyritic Olivine, from
Vestri Skardsheidi,
Raudimelur.
Basalts with macroporphyritic Olivine and Bytownite,
Chrysophyric picrite-basalt from *Grindavik*,
Olivine Trachybasalt from *Raudimelur*.
Analyses; Comparisons of "Norms" and "Modes."

V. Acid Intrusives in the Pre-glacial Formation, . . 292
Wide range embraced by the term "Liparite."
Pitchstone with fresh vitreous base, from
Drapuhlidarfjall,
Baula,
Nedri Hals.
Pitchstone with spherulitised base, from
Drapuhlidarfjall,
Nedri Hals.
Explanation of the two Types of Spherulites observed.
Miscellaneous Acid Rocks,
Felsophyre from *Baula*,
Soda-trachyte from *Snæfellsjökull*,
Trachyandesite from *Snæfellsjökull*.

Digitized by Google

PAGE

VI. Acid Lava from the Post-glacial Formation, - - 300
Mackenzie's discovery of the *Torfajökull* Region.
Soda-trachyte from the *Dómadalshraun*.
Phyric Obsidian from the *Dómadalshraun*.
Analyses of the Acid Rocks; Comparisons of "Norms" and "Modes."

VII. Palagonite-Tuff and Palagonite-Rock, - - - - - 308
Age of the "Palagonitformation."
Three Significations of the term "Palagonite."
Recommendations as to Nomenclature.
Palagonite-tuff from
Viðey,
Reykjavík.
Palagonite-rock from
Krisuvík,
Innrtholmur.
Analyses of Palagonite.
Discussion of the Data; Chemical Changes involved in Palagonitisation.

VIII. Red Partings in the Pre-glacial Formation, - - 316
Hawkes' Work.
Specimens from *Akrafjall*,
Eyilstadir.
The Red Partings an æolian Formation.

IX. Agglomerates, - - - - - - - - - - - 319
Basaltic Agglomerates.
Acid Agglomerates.

X. Mineralogical and Chemical Characteristics of the Icelandic Igneous Rocks, - - - - - - - - 321

XI. Two Distinct Volcanic Periods in Iceland, - - - 323
Geological Evidence of a Prolonged Period of Volcanic rest during the Pliocene.
Geological Evidence of the Continuity of the Inter- and Post-glacial Volcanic Periods.
Petrographic Evidence in favour of two distinct Volcanic Periods in Iceland.

XII. Summary and Acknowledgments, - - - - - - 328

XIII. References, - - - - - - - - - - - - 330

XIV. Explanation of the Plates, - - - - - - - 332

Digitized by Google

Digitized by Google

Digitized by Google

I. Introduction.

The material studied in this paper is the rock collection made by Sir George Steuart Mackenzie during a visit to Iceland during the summer of the year 1810. This collection, comprising originally some three hundred specimens, from which, unfortunately, nearly a hundred specimens are now missing, was presented by the collector to the Royal Society of Edinburgh, where it created some interest at the time (Lyell speaks of Mackenzie's "magnificent Icelandic treasures"), but seemingly escaped the notice of later geologists interested in Icelandic petrography. When the Royal Society of Edinburgh disposed of their collections some years ago, the interest of the West of Scotland was recognised, and the Hunterian Museum of Glasgow University received the custody of the Mackenzie collection. The specimens are carefully labelled, and accompanying them is Mackenzie's catalogue of localities and descriptions of the hand specimens. By means of the catalogue (Appendix to Mackenzie, 1811) it is possible to trace Mackenzie's route over Thoroddsen's geological map, and to relate the specimens with a fair degree of certainty to the various formations now recognised. The region visited by Mackenzie was the south-west of Iceland, and a map incorporating the essentials of Thoroddsen's geological survey and Mackenzie's route will be found facing page 273. To avoid unnecessary detail only such place names have been inserted as are referred to in the text.

As a pupil of Professor Robert Jameson, the ardent Wernerian who afterwards became a convert to the views of Hutton, Mackenzie was naturally attracted to the absorbing question of his time, the mode of formation of the rocks of the earth's crust; and his principal motive in visiting Iceland was the conviction he felt that in that country of intense volcanic activity he would find evidence which would render finally untenable the aqueous hypothesis of the Neptunists.[1]

[1] For a fuller account of Mackenzie's life and work, and the part he played in the Werner-Hutton controversy, see the author's "The Geology of Iceland: the Pioneer Work of a Scottish Geologist." This vol., p. 185.

Digitized by Google

Unfortunately for the petrographer, who prefers the freshest and most crystalline specimens, this motive is clearly betrayed in the collection; it contains many slags and rapidly cooled lavas, which, although affording in the hand-specimen palpable proofs of vulcanism, convey little information in thin section.

Since the pioneer visit of Mackenzie, Iceland has received a great deal of attention from geologists, first among whom is Thoroddsen (1906), whose life work is contained in his classic monograph "Island." Many valuable papers on the vulcanology and glaciology of the country have appeared, but, considering the importance of Iceland as the largest remnant of the North Atlantic Kainozoic volcanic plateau, the number of purely petrographical papers is remarkably small, and those which are available usually do not deal solely with Iceland. Disregarding the early and now superseded researches of von Waltershausen, Bunsen, and others, we have Penck's discussion of the palagonite-bearing rocks (1879), Schmidt's study of the "liparites" (1885), Bäckström's investigation of some of the acid rocks collected by Thoroddsen (1891), Wright's very full analysis of an obsidian from N. Iceland (1915), Hawkes' paper on the thin red interbasaltic partings (1916), Holmes' descriptions with analyses (1918), Lacroix's contribution with analyses (1923), and finally Washington with three analyses (1922).

Although Holmes says—"In Iceland the basaltic flows of modern times do not seem to differ in any marked way from their oldest predecessors" (1918, page 217), the writer's specimens do appear to show that the various phases of Kainozoic vulcanicity in Iceland have resulted in rocks of distinct types, and it was therefore decided to describe the specimens in groups based on chemical composition and relative age, and then, from a consideration of the chemical data to see whether this impression was justified. For this purpose the following stratigraphical subdivision has been adopted.

This subdivision dispenses with the terms "Tertiary" and "Quaternary," and replaces the "Tertiär," "Altquartär," and "Jungquartär" of Pjeturss by Pre-glacial,

Digitized by Google

TABLE I.—STRATIGRAPHICAL SUBDIVISION OF ICELAND.

	Igneous.	Sedimentary.	
Post-glacial Formation.	Hot springs, Active volcanoes, Soda-trachyte, Basaltic lava.	Aeolian, Alluvial, Fluvio-glacial, Volcano-fluvio-glacial Deposits.	Recent.
Inter-glacial Formation.	Ophitic basalt ("Doleritformation"), Tuff and Breccia ("Palagonitformation").	Conglomerate, Sandstone, Ground Moraines.	Pleistocene.
	Period of Volcanic Rest.	Marine Crag of Tjörnes with Molluscan Fauna.	Pliocene.
Pre-glacial Formation.	Basalt with Tuff partings and intrusive Rhyolite, Granophyre, Dolerite, Gabbro.	Conglomerate, Sandstone, and Clay with plant remains ("Surtarbrand").	Miocene and older.

Digitized by Google

Inter-glacial, and Post-glacial respectively; furthermore, it embodies the modern view of the age of the "Palagonit-formation" and the overlying "Doleritformation."

In the description of the collection the type specimens are considered in some detail and are frequently accompanied by a sketch of the thin section, which, in the writer's opinion, can be of more service than the usual photo-micrographs—the confusing detail of the latter may be neglected in a sketch, and important features can be emphasised. In determining the composition of the plagioclase felspars, the immersion method for finding the mean refractive index was always used. Also from each important group a specimen was chosen for chemical analysis; these analyses were conducted in the Chemistry Department of the University of Glasgow. Considering the petrographic importance of Iceland the number of good analyses available is still small; in the course of this paper almost all those have been quoted together with the new analyses, which are lettered consecutively A, B, C, &c.

II. Basalts from the Pre-glacial Formation.

Thoroddsen has mapped basalts of Pre-glacial age as "Basalt" (1901), and refers to these rocks collectively as "Die Basaltformation" (1906, page 242). Pjeturss designates the Pre-glacial foundation "Tertiär" (1910), and "Tertiary Basalt Formation" has become current in the literature. Although "Tertiary" is objectionable on account of its incongruity and lack of definition, Kainozoic cannot be substituted, as the whole of Iceland is of Kainozoic age; Bailey (1921) speaks of "Old Iceland" and "New Iceland," but as "New Iceland" readily divides into "Inter-glacial" and "Post-glacial"—the "Altquartär" and "Jungquartär" of Pjeturss—it is proposed to use "Pre-glacial Formation" for the "Tertiary Basalt Formation" of the older writers.

Thoroddsen (1906, page 243) gives us some details of the macroscopic and microscopic appearance and chemical com-

Digitized by Google

position of the Pre-glacial basalts; these appear to be drawn from Zirkel—and the only further information regarding these rocks as far as the writer is aware is provided by Holmes (1918), who gives a full description and analysis of a specimen from *Holmatindur*, *Eskifjörður*, E. Iceland. Mackenzie collected from five localities occupied by Pre-glacial basalts: (1) *Akrafjall*, *Hvalfjörður*; (2) *Stapi*, *Snæfellsnes*; (3) *Froðá*, *Snæfellsnes*; (4) *Vestri Skards-heidi*; and (5) *Egilstadir*, on the River Þjorsá.

(i) *Akrafjall.*

The mountain *Akrafjall* is situated in the Pre-glacial country on the west side of the *Hvalfjörður*. Mackenzie collected a complete suite of specimens from this locality, from which, unfortunately, many are missing. The lowest visible bed of the mountain is an agglomerate; then follows a long series of basalt sheets, often amygdaloidal, with interbedded tuffs and agglomerates (described elsewhere). Mackenzie estimates the average thickness of the beds at 20 feet, and one bed of tuff reaches a thickness of 50 feet according to him. Two specimens will be selected from this series for description.

R284,[2] taken near the foot of the series, is a dense, grey-black rock in which porphyritic felspars up to 3 mm. in length are visible. In thin section (Plate III., Fig. 1) these are seen to be bytownites of mean R.I. 1·570, somewhat corroded, and containing inclusions of pyroxene grains and palagonite specks arranged in strings parallel to the twin lamellæ. The groundmass consists of a network of small labradorite laths (average length, 0·5 mm.), the interspaces being occupied by a very pale, grey-green, granular pyroxene. Titaniferous magnetite occurs as fairly plentiful scattering of irregular grains and incipient skeletal growths, while a considerable proportion of palagonite glass is distributed through the slide. This glass is chocolate brown in colour, marginally

[2] These numbers refer to the Hunterian Museum Rock Catalogue.

Digitized by Google

isotropic, but altered internally to a polarising mineral of radial fibrous habit. Olivine could not be detected.

R300, taken from the top of the series, is a grey, slightly vesicular rock showing porphyritic felspars up to 2 mm. in length. In thin section it is similar to the above, but gives evidence of more rapid cooling. The phenocrysts are again bytownites with linearly arranged magma inclusions, while the groundmass, which is of much finer texture (average grain size, 0·03 mm.), consists of small labradorite laths with very pale intergranular pyroxene, and a plentiful scattering of equidimensional magnetite grains. Olivine was seen as a few small crystals of a size equal to that of the pyroxene.

(ii) *Stapi.*

Although Pjeturss says "Mit sehr wenigen Ausnahmen gehören alle die schönsten isländischen Säulenwände zum Quartär" (1910, page 7), Thoroddsen described the fine column ranges at *Stapi* and at *Froðá* in his chapter on the "Basaltformation," *i.e.*, the Pre-glacial Formation (1906, page 244), and failing further evidence we must accept the latter view.

Of R317 Mackenzie says—"From the columns at Stappen. Here there is still a resemblance to lava, only this contains less olivine than the lavas we had met before (1811, Appendix, page 14). R317 is a bluish grey, vesicular rock showing porphyritic felspars up to 5 mm. in length. In thin section (Plate III., Fig. 2) it is seen to be strictly comparable to R300 just described. The bytownite phenocrysts have a mean R.I. of 1·575, while the average grain size of the groundmass is 0·04. Black ore occurs as a liberal dusting of magnetite grains which often show good cubic outlines, while olivine is present as a few granules distinguishable from the pyroxene only by its lack of colour and higher double refraction. R318, taken from the base of a column, is darker and more slaggy in the hand specimen, and differs from the above only in possessing a small intersertal residuum of cryptocrystalline material.

Digitized by Google

(iii) *Froðá.*

Mackenzie says on page 16—" On a point of land several miles to the eastward of *Olafsvík* are some fine ranges of columns overhanging the sea. Some of these appear as if they had been twisted. At the only place where they were accessible, they presented an undulated appearance on the lower ends, at the separation of the columns from a bed of amygdaloid on which they rested. When broken the fracture exhibits the vitreous appearance so often observed on the sides of veins." This seems to indicate that the *Froðá* columns are of Inter- or Post-glacial age, resting on a foundation of eroded Pre-glacial basalt.

R337 is a fine-grained, dark-coloured rock with a well-marked conchoidal fracture. In thin section it appears essentially similar to R318 from *Stapi*, only it gives evidence of even more rapid cooling. The average grain size is 0·035 mm.; the bytownite phenocrysts are smaller and present nearly euhedral outlines; the proportion of cryptocrystalline and glassy base is higher; the felspar microlites and laths have well-marked fluidal orientation; and the relative amount of olivine to augite in the groundmass is greater, as is provided for in Bowen's " Reaction Series " (1922).

(iv) *Vestri Skardsheidi.*

The two specimens taken from the Pre-glacial area *Vestri Skardsheidi*, between *Svignaskard* and *Stadarhraun*, are again similar to the Pre-glacial basalts of the *Snæfellsnes* and *Hvalfjörður* districts. R309 is a dark, compact rock crowded with well-formed felspar phenocrysts reaching 1 cm. square. Fragments of these immersed in a liquid of R.I. = 1·580 all prove to have an R.I. greater than that of the liquid, and are therefore pure anorthite. The groundmass is exactly similar to that of the Pre-glacial basalts already described, olivine occurring only as very sparse, small altered crystals. The black ore has assumed a skeletal habit and hence doubtless contains titanium. R310 from the

Digitized by Google

same locality is similar to R309, but in addition is amygdaloidal, the cavities containing a variety of zeolites.

(v) *Egilstadir, River Þjorsá.*

A small Pre-glacial patch occurs at *Egilstadir* opposite *Kalfholt* on the River *Þjorsá*, where these rocks were collected. Mackenzie records a succession of amygdaloids resting on red tuff, just as at *Akrafjall*. R365 is a dark, dense rock with large circular cavities (up to 2 cm. diam.) lined with a water clear zeolite, isotropic in small fragments, and with a R.I. of 1·490, which agrees with the characters of analcite. In thin section the rock is seen to be a fine-grained aggregate of faintly greenish pyroxene and labradorite laths together with a little intersertal glass and magnetite. There are no felspar phenocrysts, and no olivine can be detected in the groundmass. R364 is a vesicular version of the same rock, but the steam cavities are empty; R366 is free from vesicles and somewhat less fresh.

TABLE II.

ANALYSES OF POST-GLACIAL ICELANDIC BASALTS.

	A.	I.	Norm of analysis A.	
SiO_2	46·07	48·79	Q	6·78
Al_2O_3	13·70	11·96		
Fe_2O_3	7·53	2·51	or	6·12
FeO	7·09	12·10	ab	13·62
MgO	5·09	5·60	an	26·97
CaO	11·79	10·15		
Na_2O	1·64	2·40	di	22·65
K_2O	0·98	0·70	hy	3·16
TiO_2	3·83	4·17		
P_2O_5	0·42	0·37	ap	1·01
H_2O+	1·12	0·40	mt	10·90
H_2O-	0·78	0·65	il	7·30
MnO	0 32	0·21		
CO_2	none	0·41	H_2O	1·90
	100·36	100·59[3]		100·41

[3] Including Cl tr.; S 0·06; Cr_2O_3 tr.; V_2O_3 0·11; NiO tr.; SrO none; BaO tr.; less O 0·02. Sp. gr., 3·03.

Digitized by Google

A. III. 4(5). 4. 4. R300, Pre-glacial basalt, *Akrafjall*, *Hvalfjörður*, Iceland. Anal. M. A. Peacock.

I. III. "5. 3(4). 4(5). Pre-glacial basalt, *Holmatindur*, *Eskifjörður*, E. Iceland. Holmes, 1918, p. 192. Anal. H. F. Harwood.

The above are the only complete analyses available of Icelandic Pre-glacial basalts. Although taken from opposite extremes of the island, they agree tolerably well, the only notable discrepancy being in the state of oxidation of the iron which in Harwood's analysis is mostly in the ferrous state, while in that of the author ferrous and ferric iron are present in about equal proportions. This accounts for the high normative value for magnetite. Holmes' rock is also more alkalic, placing it in Rang 3 transitional to 4, while the lower alkali content of the new analysis places the writer's specimen into Rang 4. Also Holmes' greater preponderance of soda over potash places his rock at the per-sodic extreme of Subrang 4, while the new analysis falls into the middle of that division. Considering the norm of the new analysis, the 6 odd per cent. of excess silica is not observed in the mode. The normative plagioclase works out at ab/an = 34/66, while the mean R.I. of fragments of the bytownite phenocrysts was 1·570, corresponding to a composition of ab/an = 25/75; the greater lime content of the latter is in keeping with their early growth. The plentiful scattering of black ores in the slide are reflected by the high normative figures for magnetite and ilmenite, but the abundance of the latter would not have been suspected without the analysis.

III. Basalts from the Inter-glacial Formation.

Overlying the "Palagonitformation," and often overrun by Post-glacial basaltic flows, are found striated ophitic basalts which Thoroddsen classed as the "Doleritformation," and to which he ascribed a Glacial and Pre-glacial age (1901).

Digitized by Google

Two years after the close of Thoroddsen's field work (1881-1898), Pjeturss (1900) found undoubted moraines in the "Palagonitformation," and hence the ophitic basalts must have been erupted in late Glacial times. The "Doleritformation" occupies large areas in central and northern Iceland, certain parts of the *Snæfells* peninsula, the northwest extremity of the *Gullbringu Sysla*, and further, Thoroddsen has found that over the whole of the latter peninsula ophitic basalts form the foundation of the younger Post-glacial basaltic flows. Mackenzie collected extensively from the *Reykjavík* district, and noted the similarity between specimens taken from various points; he also observed the boundary near *Keflavík*, *Gullbringu Sysla*, between the recent lavas and the older doleritic basalts. Thoroddsen (1905, pages 305-306) gives a general description of these rocks, and an examination of the Mackenzie specimens serves to confirm this description and to amplify it to some extent.

R260 from *Keflavík*, *Gullbringu Sysla*, is described first as it is the coarsest-grained member of the series. It is a grey, porous rock in which the felspars and the mafic minerals can be distinguished macroscopically. In thin section (Plate III., Fig. 3) it is seen to be perfectly fresh, and to consist of plagioclase, augite, and ore in that order of abundance. The felspar has a mean R.I. of 1·570, which corresponds with that of a labradorite of composition ab/an = 25/75, and occurs as a network of laths and tables. Augite appears as large pale-brown plates, showing remarkably fine ophitic relations to the felspar. Olivine is sparse, and is found as occasional aggregates of small, fresh, often perfectly euhedral crystals which were obviously the first to separate. Black ore is mostly anhedral, its outlines being determined by adjacent minerals, and is therefore the last constituent to solidify; an occasional subhedral crystal indicates, however, that some at least was of earlier growth. The order of commencement of crystallisation runs therefore: olivine—plagioclase—augite—ore.

R200 and R205 from *Reykjavík* and R241 from *Hafnarfjorður* are all similar to R260, but of somewhat less coarse texture, also the ratio of olivine to augite is dis-

Digitized by Google

tinctly higher than in the more slowly cooled example from *Keflavík*.

R202, 203, and 204 from *Reykjavík*. "On examining these specimens, which are all from the lower part of the same bed of rock (R200), they all bear the most unequivocal marks of fusion. This is the case on the whole of the lower surface; hence I conclude that this rock is a species of lava." —Mackenzie. These are slaggy versions of the coarser doleritic lava R204, showing a distinct ropy surface. In thin section, although differing greatly from the type specimen (R260 from *Keflavík*), they are seen to be the logical result of rapid cooling of the same magma which produced the coarser rock. Labradorite is seen as a network of small laths and microlites, often fading terminally into the plentiful cryptocrystalline groundmass. Olivine is plentiful, occurring as numerous fresh, rounded crystals; a very little granular augite is found in the interspaces between the felspars, representing the first stage of ophitic growth; ores as such are absent, their constituents doubtless being contained in the more opaque parts of the groundmass. The order of commencement of crystallisation in R260 was clearly seen to be olivine—plagioclase—augite—ore; in this case precisely the same order holds, only solidification took place at an earlier stage, when augite had just commenced to crystallise and the ore minerals were still held in solution.

R206, 207, 208, and 211 from *Reykjavík* "are from the bed of rock under A1 (R200). It seems to be the same, only entirely vesicular. . . . This bed may readily be distinguished by its columnar form. . . . Some of the specimens contain specks of a brilliant golden lustre which are olivine in a state of decomposition."—Mackenzie. In thin section these rocks agree in all essentials with the above; the olivine, however, is not altered as Mackenzie says, but perfectly fresh. R259, taken on the road from *Grindavík* to *Keflavík*, is indistinguishable from the above four rocks.

R211 from *Reykjavík*. In this the cooling has been still more rapid, complete solidification having taken place before any pyroxene had commenced to crystallise. The section consists mainly of a dark brown, faintly translucent to

Digitized by Google

opaque glass, charged with microlites of plagioclase and an approximately equal proportion of the earliest constituent olivine.

R244, contained in an agglomerate from *Keflavik* (described on page 320), represents the vitreous facies of the ophitic basalt, and contains olivine aggregates as almost the only crystalline constitutents of a brown, structureless glass

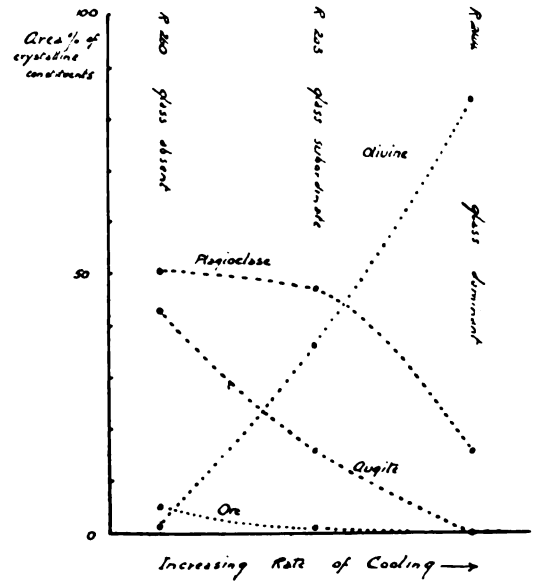


Fig. 18.—Diagram of proportions of minerals from the same magma at different cooling rates.

base; a very little felspar and pyroxene is found, but the quantity is negligible compared to that of the olivine.

These variations in the relative proportions of minerals crystallising from the same magma, but at different cooling rates, may best be illustrated by a diagram (Fig. 18). The ordinates are percentage areas of crystalline constitutents,[4] while the abscissæ give a qualitative measure of the rate

[4] These were obtained by drawing typical sections on squared paper, by means of a reflecting apparatus on the Abbé principle, and counting squares.

Digitized by Google

of cooling as indicated by the average grain size, and by the ratio of phenocrysts to cryptocrystalline or glassy base. The most striking feature is the antipathetic relationship between olivine and augite. In R244, where the high temperature conditions were retained by rapid cooling, just as in the quenching of a metallic alloy, olivine is distinctly dominant, while pyroxene is absent; in R260, where cooling was slow enough to allow approximate equilibrium to be attained, olivine is negligible in amount, whereas augite occupies nearly half the rock. The explanation for this is to be found in the " Reaction Principle " summarised by Bowen in a recent paper (1922, page 198). Briefly he recognises two reaction series: the continuous series of the plagioclases, and the discontinuous series of olivine—pyroxene—amphibole—mica. We are here concerned with the second series. It was abundantly clear in the sections considered above that olivine was the first mineral to form. In the rapidly cooled examples this early formed olivine was retained, while in the more slowly cooled rocks there was time for the early formed olivine to react with the liquid, and to form pyroxene with the adsorption of free silica in solution. It therefore appears that the presence or absence of olivine in certain basalts may be quite fortuitous, depending on the length of the cooling period, and cannot therefore, in these cases, be regarded as of basic classificatory value. This very point is emphasised in a paper by Washington just to hand (1923, page 470), but the writer restates it as he had just completed the micrometric measurements, and constructed the diagram, when he received the paper.

R220 from *Viðey*, off *Reykjavík*, probably represents the hypabyssal equivalent of the ophitic basalts described above. Mackenzie described it as " columnar greenstone," and states that " it contains small specks of a black vitreous substance, the fracture of which is conchoidal." Macroscopically this rock is dark, compact, and coarse-grained, felspar, augite, and the above vitreous specks, being clearly seen. In thin section (Plate III., Fig. 4) tables of labradorite, mean R.I. = 1·560, composition ab/an = 45/55, and plates of augite are seen in approximately equal proportions, the grain size

Digitized by Google

being about 1 mm.; ophitic relations are often well developed. Black ore, which when powdered is indifferent to the magnet and is therefore ilmenite, is seen as long straight needles of early growth, and as cubes, rhombs, and various skeletal forms, some of which are certainly of early formation, while others are just as certainly of late consolidation. Occupying the interspaces is found a cryptocrystalline to glassy residue, the above "black vitreous specks," which is often present as palagonite, the same red-brown, fibrous mineral which constitutes the bulk of the palagonite rock from *Krisuvík* (R253, page 311). The palagonite often shows well-marked growth lines producing an agate structure. Olivine is entirely absent, as would be expected from the coarse grain, indicating that cooling had been, up to the point of effusion, sufficiently slow to allow of complete reaction between the presumably early formed olivine and the liquid. R216, 227, 228 from the same place differ from above only in grain size, and in the proportion of palagonitic residue carried. On account of the notable proportion of palagonite carried, these rocks may be termed "palagonite-dolerite."

TABLE III.

ANALYSES OF ICELANDIC INTER-GLACIAL OPHITIC BASALTS.

	B.	I.	II.	Norm of analysis B.	
SiO_2	45·82	48·06	45·10	ne	1·14
Al_2O_3	15·30	12·14	9·58	or	8·90
Fe_2O_3	0·89	4·89	5·37	ab	14·67
FeO	11·97	9·04	10·59	an	28·36
MgO	7·86	9·80	14·24		
CaO	10·81	12·23	10·18	di	18·56
Na_2O	1·96	2·07	2·31		
K_2O	1·46	0·31	0·19	ol	20·73
TiO_2	2·61	1·55	2·17		
P_2O_5	0·44	0·07	0·17	mt	1·39
H_2O+	0·24	0·10	0·49	il	5·02
H_2O-		0·04		ap	1·01
MnO	0·38	0·17	0·16		
CO_2	none	none	n.d.	H_2O	0·24
	99·74	100·48[5]	100·55		100·02

[5] Incl. BaO none; S 0·01; Cr_2O_3 none; V_2O_3 n.d.; ZrO_2 none.

Digitized by Google

B.	III.	5.	″4.	″4. R260, Inter-glacial ophitic basalt, *Keflavík, Gullbringu Sysla*, Iceland. Anal. M. A. Peacock. Described on p. 282.
I.	III.″	5.	4.	″5. Pre-glacial[6] basalt, *Reykjavík*, Iceland. Washington, 1922, p. 783. Anal. Washington.
II.	(III.) IV.	[5.	3″.	5.] Doleritic basalt, *Hafnarfjörður*, Iceland. Lacroix, 1923, p. 373. Anal. Raoult.

The above are the only complete analyses available of the Inter-glacial doleritic lavas. The figures show that these rocks are somewhat variable in composition, analyses B. and I. being fairly comparable, but analysis II., with its high magnesia and low alumina, showing a distinct melanocratic divergence. All three agree, however, in showing a deficit of normative silica, producing normative olivine, while the analyses of the Pre-glacial basalts gave an excess of silica producing normative quartz and no olivine. Considering the norm of the new analysis B., the calculated plagioclase is, as was found before, somewhat more alkalic than that determined by refractive index measurements. The amount of calculated olivine is greatly in excess of the amount observed in the slide, which was cut from a coarse, slowly cooled specimen in which the presumably abundant early formed olivine had reacted with the liquid to form pyroxene, but it fairly represents the olivine content of the more rapidly cooled products of the same magma.

IV. Basalts from the Post-glacial Formation.

Basaltic lavas of Post-glacial age occupy large areas in central and southern Iceland. Mackenzie collected specimens chiefly from four districts—the *Gullbringu Sysla*, the

[6] The basalts around *Reykjavík* are mapped by Thoroddsen as "Pre-glacial Dolerite," but on account of Pjeturss' discovery of moraines in the older "Palagonite Formation," the ophitic basalts must be considered as Inter-glacial in age.

Digitized by Google

Hnappadals Sysla, the *Myra Sysla*, and the *Hekla* district. These rocks invariably carry olivine which is present as fresh macrophenocrysts, as somewhat altered microphenocrysts, or as nucleii in the pyroxene of the groundmass.

Basalts with macroporphyritic olivine.

R308 from *Vestriskardsheidi, Myra Sysla*, is a fresh, fine-grained, vesicular rock in which are seen phenocrysts of olivine which reach 3 mm. in greatest diameter. In thin section olivine is seen to be the only phenocrystic constituent; it appears as numerous rectangular to rounded shaped, colourless sections which are often slightly altered terminally or marginally to a very pale green or brown mineral which is indistinguishable from the pyroxene of the groundmass. This appears to be an example of early formed olivine reacting later with the liquid to form pyroxene with the adsorption of free silica. The groundmass consists of a fine-grained aggregate of labradorite laths with about an equal proportion of greenish intergranular pyroxene; in addition there is a notable residuum of almost opaque glass which doubtless contains the components of the absent ore minerals. Occasionally wedged between the felspars are found small areas of an isotropic zeolite of very low R.I.

R311 from *Raudimelur, Hnappadals Sysla*, contains numerous crystals of tarnished olivine which attain to ½ cm. in size, and an occasional phenocryst of pyroxene. In section the olivines are seen to be often euhedral, and to have altered terminally and along cracks, with a copious separation of magnetite which is sometimes oxidised to hæmatite; phenocrystic pyroxene is represented in the section by a single, large, pale-green crystal. The groundmass is again intergranular in texture, the pyroxene in it being either greenish or yellow due to alteration. Black ore appears to be very plentiful, but from its lack of euhedrism much of it must be ascribed to opaque glass and highly altered olivine.

Basalts with macroporphyritic olivine and bytownite.

R258 from *Grindavik, Gullbringu Sysla*, is a grey, friable rock densely charged with fresh, green, equidimensional

Digitized by Google

crystals of olivine of 3 mm. mean diameter; as subordinate phenocrystic constituents are found crystals and aggregates of plagioclase somewhat larger than the olivine. In this section (Plate III., Fig. 5) olivine is subhedral and almost perfectly fresh; it shows good cleavages on prismatic sections, and grades in size from macro- to micro-phenocrystic dimensions. Plagioclase is subordinate to olivine in quantity, and is found as aggregates of slightly corroded calcic bytownites of mean R.I. 1·575. The groundmass is of fine, subophitic texture, pyroxene preponderating over the labradorite microlites and laths; black ores are very sparse, and the few equidimensional grains present indicate the absence of much titanium. Under the name " chrysophyric picrite basalt " Washington has described a rock from Kilauea, Hawaiian Islands; although perhaps somewhat richer in olivine, and hence in magnesia, than the Iceland example, the latter accords closely enough with the Hawaiian occurrence to warrant the application of Washington's term (1923, pages 344-347).

Olivine-trachybasalt.

R312 from *Raudimelur, Hnappadals Sysla*, was selected by Dr. Tyrrell for comparison with a similar rock from Jan Mayen, and on account of its porphyritic olivine and mildly alkalic character as revealed by the analysis, was tentatively designated olivine-trachybasalt. The hand-specimen is a grey, compact rock with small phenocrysts of somewhat altered olivine and of felspar. In section olivine tends to be euhedral, and occurs as sparse microphenocrysts and as minute specks in the groundmass. The larger felspars are bytownites of R.I. 1·570, while the smaller tables and laths of the groundmass are distinctly more alkalic and are sometimes untwinned, and hence contain the potash of the analysis. Pyroxene is very subordinate to felspar in the groundmass, and is represented by a host of minute euhedral prisms of green ægerine-augite of early growth poikilitically related to the felspar.[7]

The remaining Post-glacial basaltic lavas are a series of slags from *Hekla*. A few sections were cut, but they give no

[7] Black ores are present as a plentiful scattering of small grains.

Digitized by Google

information; they consist of highly vesicular glasses almost opaque, due to copious separation of black ore, in which specks of pyroxene and felspar are the only other recognisable constituents. Washington's analysis, to be quoted presently, throws some light on these rocks.

TABLE IV.

ANALYSES OF POST-GLACIAL ICELANDIC BASALTS.

	C.	I.	II.	III.	IV.	D.	V.
SiO_2	43·83	47·27	47·67	49·56	47·68	46·38	53·39
Al_2O_3	14·70	14·44	15·81	10·36	12·54	15·06	13·37
Fe_2O_3	1·47	0·97	1·70	7·04	3·44	2·76	2·07
FeO	6·81	10·15	10·41	8·19	12·34	9·73	10·62
MgO	19·08	10·30	8·08	6·04	5·25	6·75	3·30
CaO	11·85	11·73	12·23	11·66	9·58	9·74	6·90
Na_2O	1·18	1·86	1·98	1·86	2·43	3·07	3·84
K_2O	0·14	0·18	0·27	0·63	0·88	1·02	1·19
TiO_2	0·46	2·36	2·17	4·16	5·01	3·68	2·28
P_2O_5	0·05	0·12	0·10	0·06	0·23	1·07	1·24
H_2O+	tr.	0·33	0·21	0·29	0·44	tr.	1·37
H_2O-	0·25	0·09	0·10	0·25	0·15	0·35	0·08
MnO	0·12	0·19	0·16	n. d.	n. d.	0·42	0·20
CO_2	none	none	n. d.	n. d.	n. d.	none	none
	99·94[8]	100·12[9]	100·89	100·10	99·97	100·03[10]	99·85

C.	III.″	5″	4 (5)	″5. R258, chrysophyric picrite-basalt, *Grindavík, Gullbringu Sysla.* Iceland. Anal. W. H. & F. Herdsman.
I.	III.	5.	4.	5. Olivine-basalt, *Grundafjord*, W. Peninsula, Iceland. Holmes, 1916, p. 196. Anal. Harwood.
II.	III.	5.	4.	″5. Basalt, *Allmannagjá*, near *Þingvellir*, Iceland. Washington, 1922, p. 783. Anal. Washington.

[8] Including ZnO none; (Ni Co) O tr.; S tr.

[9] Including BaO none; SrO none; S none; Cl 0·01; NiO 0·01; Cr_2O_3 0·04; V_2O_3 0·07.

[10] Including (Ni Co) O tr.; S tr.

Digitized by Google

III.	III.	4.	(3) 4.	4. Basalt, eruption of 1783, *Skaftareldhraun*. Lacroix, 1923, p. 373. Anal. Raoult.
IV.	III.	5.	3 (4).	4. Glassy basaltic scoria, eruption of 1918, *Katla*, Iceland. Lacroix, 1923, p. 373. Anal. Raoult.
D.	'III.	5.	3″.	4″. R312, Olivine-trachybasalt, *Raudimelur*, Iceland. Anal. W. H. & F. Herdsman.
V.	II. (III).	(4) 5.	″3.	4. Basalt, recent *Hekla* lava, near *Noefrholt*, Iceland. Washington, 1922, p. 783. Anal. Washington.

TABLE V.

NORMS OF THE NEW ANALYSES.

	C.	D.
or	0·84	6·12
ab	3·67	25·68
an	34·19	24·46
ne	3·41	—
di	18·80	14·25
hy	—	4·18
ol	35·25	11·73
mt	2·09	3·94
il	0·91	6·99
ap	0·34	2·35
H_2O	0·25	0·35
	99·75	100·05

The above are the now available good analyses of the Post-glacial basalts. The norm of the picrite-basalt R258 (norm C) gives 35·25 per cent. of olivine, and 37·5 per cent. of plagioclase of composition ab/an = 10/90; this accords well the relative amounts observed in the slide (page 288), and the agreement between the calculated composition of the felspar and the measured value (R.I. = 1·575, comp. ab/an = 14/86) is good. The sparseness of black ores is reflected by the low magnetite value, and the absence of ilmenite in the slide indicates that the titanium of the analysis, which

Digitized by Google

is low for an Icelandic basalt, is held in the pyroxene. The norm of the olivine-trachybasalt R312 reveals this rock's mildly alkalic tendency, but the normative felspar which works out at ab/an = 51/49, errs on the alkalic side, due to all the soda being allotted to albite, while in the case of this rock it appears notably in the green pyroxene.

V. Acid Intrusives in the Pre-glacial Formation.

Although much the larger proportion of the rocks of Iceland are basalts and basaltic tuffs, acid activity has taken place in a minor degree from earliest times. Whereas the Post-glacial acid types are true lavas, and are restricted to a single district, the *Torfajökull*, which occurrence was discovered by Mackenzie, the older acid types, pitchstone, soda-trachyte and granophyre are almost invariably intrusive in character, and are exposed in very numerous small areas throughout the Pre-glacial country. Mackenzie discovered four of these areas—*Snæfellsjökull*, *Drapuhlidarfjall*, *Baula*, and *Nedri Hals*, the first three of which are conspicuous mountains in the western Pre-glacial country, while *Nedri Hals* lies at the head of a small inlet off the eastern shore of the *Hvalfjörður*. *Snæfellsjökull* is an ancient volcano forming the terminus of *Snæfellsnes*; although dominantly basaltic it has evinced acid activity, and Bäckström has described specimens collected from this locality (1891). *Drapuhlidarfjall*, situated S. of *Stykkisholmur* in the *Snæfells Sysla*, is mapped by Thoroddsen as "Liparit," but descriptions of thin sections do not appear to have been published. *Baula* has received attention from Schmidt (1885), but the area at *Nedri Hals* seems to have been missed by all later geologists, including Thoroddsen.

The Icelandic acid rocks have hitherto been discussed only by continental writers who designate them collectively as "Liparit," but as this term is used in this case to embrace rocks varying in texture from granophyre to obsidian, and in composition from rhyolite to trachyte, and even trachyandesite, it seems desirable to abandon the term in favour of more narrowly defined terms.

Digitized by Google

The rocks to be described vary greatly in macroscopic appearance, but resemble one another closely in mineral content; in this respect they differ also, but slightly, from the Post-glacial acid lavas of the *Torfajökull* to be described later. As each of the four localities affords examples of more than one rock type, the specimens will be described under rock headings in preference to locality headings.

Pitchstone with fresh vitreous base.

R351 from *Drapuhlidarfjall* is a chocolate-brown glass with marked perlitic and conchoidal fracture. In thin section the glass in seen to be pale-brown and entirely free from microlites. Within the glass series of spheroidal cracks have developed producing exceptionally fine perlitic structure; the larger cracks are marked by films of a brown material which proves to be markedly doubly refracting, its structure being fibrous, the fibres growing normal to the direction of the cracks.

R349 from *Drapuhlidarfjall* is described by Mackenzie as an "ash-grey pearlstone." The specimen is a buff-coloured pitchstone free from macro-phenocrysts. As micro-phenocrysts there are felspars, pyroxenes, and ores. Felspar is seen firstly as sparse, euhedral, although marginally corroded, untwinned crystals of orthoclase crowded with magma inclusions; and, secondly, as corroded crystals of anorthoclase showing extremely fine cross-hatched multiple twinning. Pyroxene is represented by the pale-green variety, the soda-bearing ægirine-augite, as a few subhedral prisms, while magnetite is found as granules and cubes attached to, or embedded in, the boundaries of the prisms of pyroxene. The groundmass is a reddish-brown glass; it reveals an ill-defined banding due to bands and patches of a totally isotropic dark-brown glass alternating with similar areas of a lighter, somewhat devitrified glass; the latter has a mottled appearance due to the formation of numerous incipient micro-spherulites. R350 from the same place agrees entirely with the above in the hand-specimen; in thin section it differs only in being completely free from micro-phenocrysts.

Digitized by Google

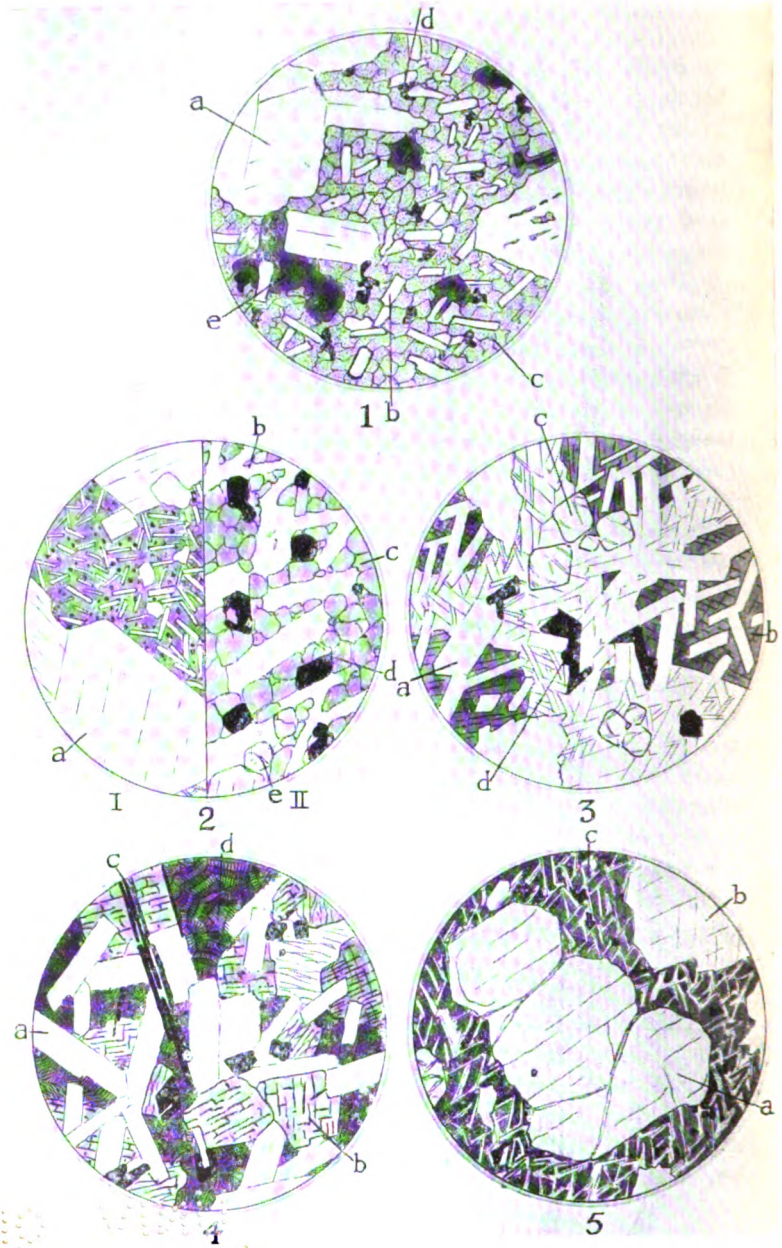
R359 from the W. side of *Baula* is a perfect bottle-green glass showing plentiful felspar crystals of reddish colour due to iron staining. The thin section (see also Schmidt, 1885, pages 749-753) reveals two generations of felspars; firstly, single and aggregated crystals of orthoclase, often with exceptionally euhedral boundaries, and, secondly, a host of smaller laths and tables which Schmidt also classes as orthoclase. Although their extinction angles are always zero or small, the writer's sections showed several cases of undoubted multiple twinning, and he regards them as crystals of an acid oligoclase. This appears to provide a case of the reversal of the usual order of crystallisation, in which the more basic felspar appears in the first generation, while the less basic is found in the second. Pyroxene is represented by numerous prisms similar in size and shape to those forming the second generation of felspars; instead of the green, strongly pleochroic, monoclinic ægirine-augite, we find an orthorhombic mineral with low colours, agreeing with the characters of hypersthene. Magnetite is seen as perfect minute cubes sparsely scattered throughout the mass; as was observed before, there is a tendency for the ores to attach themselves to the borders of the pyroxene crystals. The glass in which these minerals are embedded is perfectly fresh and colourless; in the case of R358 from the same locality well marked perlitic cracking had developed.

R277 from *Nedri Hals*. Although not fresh, this rock has been included here as the following section is devoted to rocks showing spherulitic alteration. The specimen is a pitchstone of marked platy structure, the plates preserving a uniform thickness of 4 mm.; the planes of division between adjacent plates are brown, due to invading iron-bearing solutions. A fresh fracture across these planes shows a rock of dingy, featureless appearance. The section reveals a few greatly resorbed crystals of orthoclase and albite embedded in a groundmass in which the original glass has been altered to an extremely fine-grained aggregate of quartz, alkali-felspar, and ore; although divitrification is almost complete, it has taken place without producing perceptible spherulitic alteration.

Digitized by Google

Univ. of California

Digitized by Google



Digitized by Google

Pitchstone with spherulitised base.

R352, 353, 354, from *Drapuhlidarfjall.* Of these Mackenzie says—"This rock was immediately above the preceding." "The preceding" are R350, 351, described above; they are respectively a pitchstone in which spherulitic recrystallisation had just commenced, and a perfectly fresh perlite, and the specimens to be described are clearly the result of advanced alteration of the holovitreous perlite.

The hand-specimen shows a few irregular bands of dull pitchstone separated by broader bands and areas of light-grey, earthy appearance. On fracturing the specimen, which took place through the weak earthy bands and without the aid of the hammer, parts of the spheroidal surfaces of many spherulites were exposed. These spheroidal surfaces could often be scratched with the finger-nail; this was due to the presence of a soft, white clay covering parts of the surfaces and occasionally wedged in the angular spaces between adjacent spherulites. In two cases examples were observed of what appeared to be hemi-spherulites, their flat faces being bounded by a band of less altered pitchstone. These hemi-spherulites, which could not be considered proper to the rock in which they were contained, were temporarily explained as having been weathered from a pre-existing spherulitic rock, broken in transport, and caught up by a later acid flow. Examination of the thin section, however, suggested another explanation.

Plate IV., Fig. 6, indicates the appearance of the slide under crossed nicols. It will be observed that the original glass was free from phenocrysts and microlites (as was R351, the fresh perlite above which it was found), and that the whole rock has suffered secondary crystallisation with the formation of two distinct types of spherulites. Firstly, at numerous points within the rigid liquid radiating fibres have commenced growth; these are extremely minute and appear to be largely or entirely felspathic, although indeterminable quartz may be present. As growth has continued the radiating spherulites have interfered and a sheaf-like structure has been produced. This sheaf fabric, which is clearly appreciable only under

Digitized by Google

crossed nicols, is purely the result of a change from the unstable vitreous condition to the stable crystalline condition, and is therefore of secondary origin; the fibres of which it is composed give straight extinction as would fibres of alkali felspar. Plate IV., Fig. 6, also shows a patch of the interstitial clay observed in the hand-specimen. It would be expected that fracture would follow the surface of weakness produced by the clay, and that the fractured surface would present a botryoidal appearance due to the internal sheaf structure. Closer inspection of the hemi-spherulites mentioned above revealed this botryoidal surface; they proved in fact to be aggregates of small interfering spherulites, the mass of which had fortuitously assumed a hemi-spherical form due to the nucleus of spherulitic alteration having been close to a band of rock less favourable to spherulitic growth. The right-hand part of the figure shows such a band; in it crystallisation has taken place, but polarised light reveals no ordered spherulitic or sheaf structure.

The second type of spherulite differs from the above in being smaller, rarer, markedly concentric in structure, and in possessing a strong, black extinction cross which is inclined to the cross wires at about 20°. In ordinary light these spherulites are seen to possess a dark brown circular nucleus composed of radiating iron-bearing microlites; surrounding this almost uniformly dark centre lies a very light coloured concentric ring; the next ring is darker again and towards its outer margin the radiate structure is lost.

Concentric banding in primary spherulites produced by the rapid cooling of viscid magmas is readily explained; rapid cooling produces a rush of crystallisation of the mineral to be first saturated with respect to the liquid; this in turn results in a release of heat sufficient temporarily to arrest crystallisation, and when the temperature has fallen sufficiently to permit further separation, the crystals formed are of different composition, being poorer in the constituent first to crystallise. The spherulites in question are, it is thought, secondary in origin, as none of the fresh, glassy rocks from the locality show a vestige of primary spherulitic crystallisation, and an explanation for the concentric banding

Digitized by Google

must be sought elsewhere. In the first pitchstones to be described, it was observed that the iron-bearing minerals were restricted to a few centres—usually a pyroxene crystal surrounded by a cluster of magnetite cubes. Now if the liquid which produced these crystals was quenched from a temperature just above that at which the iron-rich minerals would have begun to crystallise, we should have a glass in which the iron-rich molecules were concentrated at a few centres. Just as the iron-bearing minerals would have been the first to separate from the mobile liquid, these same minerals will be the first to crystallise from the rigid liquid (glass). The writer therefore explains the concentric banding in the secondary spherulites described in the following way. A rise in temperature (caused by the succeeding lava flow) in the holovitreous glass containing centres of high iron concentration results in the separation at the point of highest concentration of radiating microlites of an iron-bearing mineral; the mineral formed at the centre would attempt to maintain its composition, and to do so would withdraw iron-bearing molecules from the surrounding glass. This results in a dark, uniform centre surrounded by a light coloured concentric zone. Further rise in temperature will permit crystallisation of the remaining iron-bearing molecules producing another dark concentric ring and exhausting the store of the ferriferous concentration.

R355 from *Drapuhlidarfjall* is a dark, rather porous, banded rock which is crowded with light-grey circular patches of an average size of 2-3 mm. In thin section these patches prove to be spherulites of the first type described above. They appear to be wholly felspathic, and the radial arrangement of the felspars is well marked only at the centre of each patch. Surrounding each spherulite is a zone of opaque microlites of ore; this accounts for the almost tachylytic appearance in the hand-specimen of the areas surrounding the spherulites. Finally, there are seen occasional small areas of anhedral quartz situated between adjacent ore-rich zones. From this it would appear that in the course of growth the spherulites had selected only felspathic material for themselves and had rejected the alien ores and quartz in the process.

Digitized by Google

R287 from *Nedri Hals* is more compact than the above, and the sinuous banding which it shows is emphasised by streaks of ferruginous material deposited from iron solutions derived from neighbouring basalts. Spherulites cannot be appreciated in the hand-specimen, but the thin section reveals a large number of small circular patches which polarised light shows to be of radial structure. These spherulites are darker in colour than the surrounding groundmass due to an irregular radial meshwork of an indeterminable, dingy, isotropic material which traverses them. The lighter intervening sectors are composed of radially arranged prisms of alkali felspar. The groundmass in which the spherulites are embedded is highly acid; small anhedral plates of quartz are predominant, with subordinate alkali felspar and granules of black ore. Red ferruginous films traverse the groundmass and occasionally invade the spherulites.

Miscellaneous Acid Rocks.

R360 from *Baula* is a fresh, light-grey, compact rock which in thin section appears as a felsophyre, consisting almost entirely of felspar and quartz, without pyroxene, and with only an occasional larger cube of magnetite, and a sparse scattering of smaller grains of ore. Untwinned or simply twinned felspars are found as aggregate microphenocrysts embedded in a groundmass of alkali felspar and quartz which grade from easily recognisable prisms and plates down to microfelsitic dimensions.

R280 from *Nedri Hals* gives the impression in the hand-specimen of a basic glass; under the microscope, however, it is seen to be an acid glass containing a few corroded alkali felspar proper to its composition. The dark colour of the specimen is due to an extraordinary number of basic xenoliths—fragments of basalt, and fragments of minerals proper to basalt, calcic felspars, skeleton ilmenite, and occasional olivine and common augite. The original sharpness of the boundaries of these fragments has been rounded by the acid magma, and thus the alien minerals present outlines quite similar to those of the corroded alkali felspars belonging to the acid glass.

Digitized by Google

R326 from *Snæfellsjökull* differs from the preceding rocks in being distinctly more basic, belonging more properly to the soda-trachytes than to the rhyolites. The hand-specimen is light-grey, compact, and fine-grained, with a few larger, clear felspar phenocrysts. In thin section the fabric is seen to be markedly trachytic, the bulk of the rock consisting of orthoclase microlites with good fluidal orientation. As accessory minerals in the groundmass there are numerous flakes of biotite similarly oriented, and also a fair scattering of magnetite granules. Anorthoclase is seen as occasional aggregates of larger, clear crystals with the characteristic, extremely fine, crossed twinning, while ægirine-augite is represented by a few green prisms to which are attached occasional larger cubes of magnetite. Bäckström (1891, pages 658-660) has described a "Liparit" from another part of *Snæfellsjökull;* his specimen did not contain biotite, but he remarks that the trachytic structure, and the abundance of pyroxene, of which he noted a yellow and a green variety, and the low silica content of the analysis "stellen diesen Liparit an die Grenze gegen die echten Trachyten."

R325 "from a stream of lava that has flowed from Snæfell Jokul" (Mackenzie) is still more basic than the preceding specimen. The hand-specimen is a grey, exceedingly fine-grained rock of somewhat platy fracture, exhibiting a few minute phenocrysts of clear felspar. In thin section these are seen to be plagioclase of mean R.I. = 1·555, which corresponds with that of an andesine of composition ab/an = 60/40; as microphenocrysts occur also small crystals of the typical soda-pyroxene ægirine-augite. These are set in a fluidal groundmass which is dominantly felspathic, grading in texture from easily recognisable twinned laths of straight extinguishing oligoclase to isotropic glass; subordinate in the groundmass are found intergranular pyroxenes, small crystals of what appears to be a brown, altered amphibole, and specks of black ore. With these characters the rock may properly be termed a trachyandesite.

Before giving the chemical data of the Icelandic acid rocks, the Post-glacial acid lava of the *Torfajökull* district will be described.

Digitized by Google

VI. Acid Lava from the Post-glacial Formation.

The search for obsidian and the hope that he would find it under such conditions as would render the aqueous theory of Werner untenable was one of the chief objects of Mackenzie's visit to Iceland; and in this he was eminently successful, being fortunate enough to discover the only place of occurrence of true acid lava now known, the neighbourhood of the *Torfajökull*, some 15 miles E. of *Hekla*. Fig. 19 shows that area as mapped by Mackenzie in 1811, and by comparison with Thoroddsen's map, Fig. 20, it will be seen despite the great discrepancies that Mackenzie reached the *Dómadalshraun*, the most northerly of the three Post-glacial acid flows which occur in this district. Leaving *Næfrholt*, a small hamlet a few miles to the W. of *Hekla*, Mackenzie and his companions made the double journey to the *Dómadalshraun* and back, a distance of 40 miles (60 miles on Mackenzie's map), in one day, and then climbed *Hekla* the next. Mackenzie's enthusiasm may be best gauged by his own words—"While we advanced, the sun suddenly broke through the clouds, and the brilliant reflection of his beams from different parts of this supposed lava,[11] as if from a surface of glass, delighted us with the instantaneous conviction that we had attained one of the principal objects connected with the plan of our expedition to Iceland. . . . Our discovery of obsidian afforded us very great pleasure, which can only be understood by zealous geologists; and we traversed an immense and rugged mass of that curious substance with a high degree of satisfaction" (1811, pages 242-243).

Since the discovery of this district by Mackenzie, Schythe in 1846 found the *Hraftinnuhraun*, the largest of the Post-glacial acid lava flows, while Thoroddsen discovered the *Namshraun* and rediscovered the *Dómadalshraun* in 1888 (1891, page 610). The most important work on the rocks of this district has been done by Bäckström (1891), who studied part of the material collected by Thoroddsen. Wright (1915) provides an exceptionally complete analysis of an

[11] From a distance Mackenzie mistook the obsidian for an ordinary basaltic lava.

Digitized by Google

TORFA JÖKULL
after Mackenzie 1811

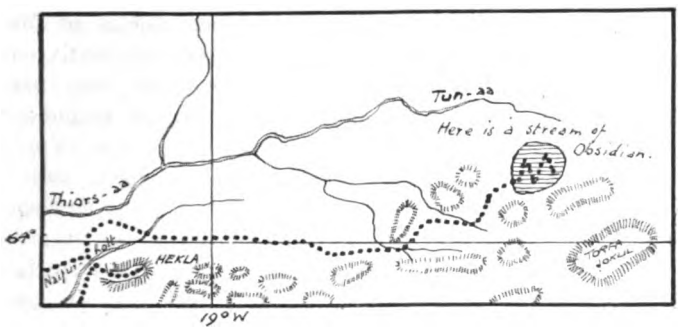


Fig. 19.—E. to W. = 38 miles.

TORFA JÖKULL
after Thoroddsen 1901

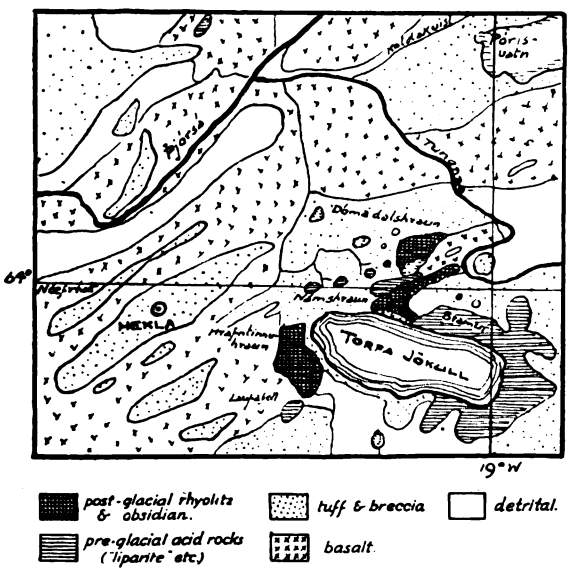


Fig. 20.—E. to W. = 32 miles.

Digitized by Google

Icelandic obsidian, but the work of Bréon (1884), as far as it concerns these rocks, and that of Schmidt (1885), has been largely superseded, their analyses being too incomplete for modern purposes.

The *Dómadalshraun* lava is an acid trachyte: the most crystalline facies is a light-grey, porous rock in which small, clear felspars are recognisable in an aphanitic groundmass. It is covered by a thick layer of phyric obsidian, which in turn is often overlain by a pumiceous crust. Mackenzie's specimens show, in addition to the above types, transitions between the various facies, such as schlieren of pumice running into the obsidian, and the bright obsidian merging into a dull pitchstone. R373 and R374 were taken from the most crystalline facies. The thin section (Plate IV., Fig. 7) reveals phenocrysts of felspar, pyroxene, and ore set in a groundmass which is highly vesicular and dominantly vitreous. The felspar phenocrysts occur as euhedral to subhedral crystals, often with slightly resorbed boundaries; they exhibit in the majority of cases close-set multiple twinning, sometimes combined with Carlsbad twinning, and extinguish at a maximum angle of 15° with the albite twinning lamellæ; fragments showing the close-set twinning when immersed in a liquid of R.I. = 1·530 are seen to have an R.I. higher than that of the liquid in one position, and lower in the other; these are the characters of the pure soda-felspar albite. Occasionally multiple twinning is extremely fine or fails entirely; fragments of such crystals have an R.I. range extending above and below a liquid of R.I. = 1·520; this indicates the presence of anorthoclase, the soda-potash felspar. Again, such crystals sometimes exhibit microperthitic structure, the inclusions being probably albite. Pyroxene is present as sparse, fresh, green, faintly pleochroic crystals which tend to form euhedral prisms; these belong to the soda-bearing variety ægirine-augite, and are identical with the pyroxene found in the Pre-glacial acid rocks. Black ore is seen as occasional well-formed cubes of magnetite sometimes partly enclosed by felspar indicating the early growth of the ore. The groundmass consists of a highly vesicular acid glass which is charged with felspar microliths;

Digitized by Google

these rarely show twinning and always extinguish at zero or at small angles, indicating orthoclase with perhaps an admixture of the soda molecule. Quartz was not observed.

R368 and R369 which Mackenzie describes as "the most common variety in the great stream which we saw." There specimens are black phyric obsidians charged with felspar phenocrysts, which reach a size of 4 mm. Microscopically the crystalline constituents agree with those of the rock just described. The felspars are again dominantly sodic, and probably contain varying amounts of the orthoclase molecule; rounded outlines due to magmatic resorption are more frequent than straight edges, and inconstant chemical composition is indicated by uneven extinction; a case was observed of a prism of albite with close-set lamellar twinning embedded in a larger, geometrically similar prism of untwinned potassic felspar; colourless or pale brown glass inclusions are plentiful. Pyroxene is again represented by the green sodic variety, ægirine-augite, while magnetite occurs exactly as in the previous rock. The groundmass of the obsidian is a perfect colourless glass of R.I. = 1·497, containing many cavities which are much contorted, as would be expected in the flow of a viscid acid lava. The glass contains a second generation of felspars, which again are probably orthoclase. R371 differs from the above only in that the felspar phenocrysts are chiefly orthoclase, twinning being either absent or simple. R370 is a dull pitchstone representing an intermediate stage between the obsidian and the acid trachyte. In R372 the passage from obsidian to trachyte is seen in one specimen; the thin section taken from the trachyte shows as phenocrysts the same minerals as in the previous examples; the groundmass, however, consists in this case of a rough meshwork of reddish, crpytocrystalline bands isolating smaller, perfectly glassy areas. Of R375 Mackenzie writes as follows (1811, page 446):—"This is a remarkable and beautiful specimen, and last of the series from the stream of obsidian. It is a mass of slag, in a cavity of which some fusible matter has been isolated, and reduced to the state of glass. The cavity has been lined by it in stalactitic masses, and some of the matter has been

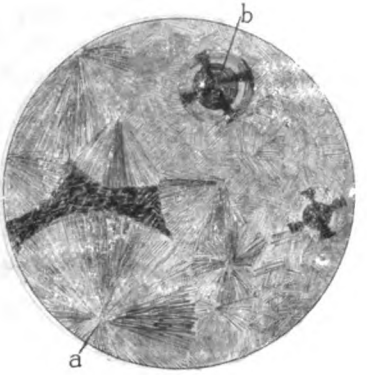
Digitized by Google

drawn out to the fineness of hair. *No operation of water could possibly produce these appearances.*" The slag referred to is basaltic, containing crystals of anorthite. It was obviously caught up by the obsidian flow, some of the molten material being trapped in a cavity in the slag; this liquid material then solidified in the act of dripping from the roof of the cavity, producing the stalactitic effect which Mackenzie noted. The hair-like material is missing from the specimen, but, as Mackenzie says, these glass threads could not possibly be explained by the Wernerian theory.

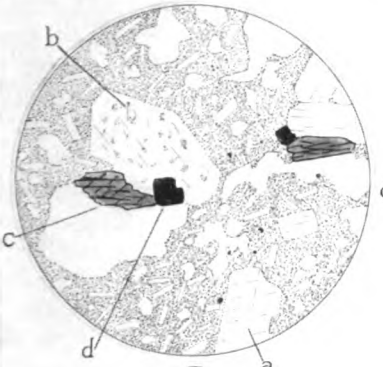
Chemical Affinities of the Icelandic Acid Rocks.

Of the acid rocks described, the Pre-glacial rhyolite R360 from *Baula* and the Post-glacial trachyte from the *Dómadalshraun* were chosen for analysis; these rocks are described on page 298 and on page 302 respectively. The rhyolite from *Baula* was selected, as it was almost the only perfectly fresh Pre-glacial specimen which did not consist largely of glass; furthermore, its high percentage of modal quartz ensured it a position at the acid end of the series. The trachyte from Dómadalshraun was chosen, as it was a product of Post-glacial acid activity, and showed modal minerals which promised it a sub-acid composition; and as Bäckström had already analysed the obsidian from the same locality, it was of interest to see how the two facies would compare in chemical composition. The analysis of R325, the trachyandesite from *Snæfellsjökull* (described on page 299), is also given; this rock was selected by Dr. Tyrrell for comparison with similar rocks from Jan Mayen, and the writer is greatly indebted to him for permission to quote the analysis from his as yet unpublished manuscript. Only three analysis of Icelandic acid rocks appear in Washington's Tables under the heading "Superior Analyses," Bäckström's numerous analyses being catalogued either as "incomplete," or "inferior," on account of the absence of values for both ferrous and ferric iron. The following table gives the available good analyses, including one by Bäckström, arranged in order of decreasing acidity; in the explanation which follows their position in the American Quantitative Classification is given.

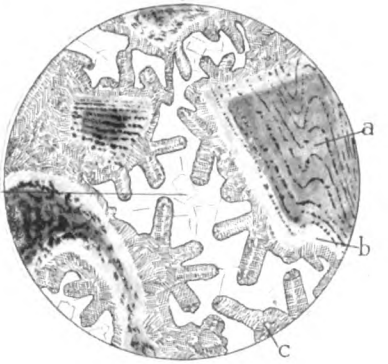
Digitized by Google



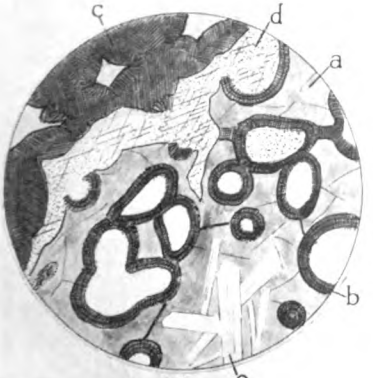
6



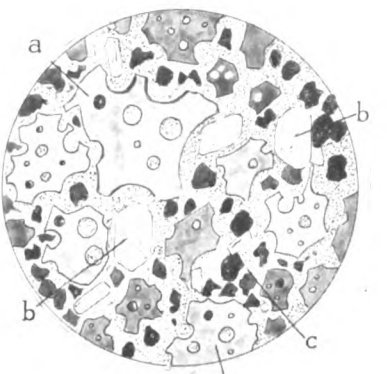
7



8



9



10

Digitized by Google

Digitized by Google

TABLE VI.

ANALYSES OF ICELANDIC ACID ROCKS.

	I.	II.	E.	III.	F.	G.
SiO_2	81·08	75·01	74·38	69·81	67·17	60·60
Al_2O_3	11·45	12·27	11·86	13·85	15·27	17·55
Fe_2O_3	n.d.	0·80	1·92	3·21	1·58	1·17
FeO	0·21	2·78	1·11	n.d.	2·41	6·08
MgO	tr.	0·08	0·19	0·43	0·85	2·04
CaO	0·46	1·87	1·26	1·38	2·33	4·02
Na_2O	2·30	3·36	4·62	5·56	6·20	3·97
K_2O	3·64	2·80	3·56	4·40	3·09	2·73
H_2O+	0·60	0·25	0·27	n.d.	0·63	tr.
H_2O-	n.d.	0·13	0·42	n.d.	0·08	0·20
TiO_2	n.d.	0·33	0·32	1·06	0·29	0·92
P_2O_5	n.d.	0·02	0·09	n.d.	0·10	0·32
MnO	n.d.	0·06	0·10	n.d.	0·08	0·35
CO_2	n.d.	n.d.	none	n.d.	none	none
	99·74	99·98[12]	100·10	99·70	100·08	99·95

I. I. 3. 1 (2). 3. Liparite, *Berufjordskard*, Iceland. C. W. Schmidt (1885), p. 776. Anal. C. W. Schmidt. Quoted in W.T.,[13] p. 63.

II. I. 3″. 2. (3) 4. Obsidian, *Hraftinnuhryggur*, Iceland. F. E. Wright (1915), p. 260. Anal. J. B. Fergusson. Quoted in W.T., p. 92.

E. I. ″4. 1. ″4. Rhyolite, *Baula*, *Myra Sysla*, Iceland. Anal. M. A. Peacock. Described in thin section on p. .

III. Norm not determinable. Liparite, *Dómadalshraun*, *Torfajökull*, Iceland. H. Bäckström (1891), p. 744. Anal. H. Bäckström. Quoted in W.T., p. 754.

[12] Including CO_2 none; ZrO_2 none; SO_3 0·07; Cl 0·13; F none; S 0·02; Cr_2O_3 none; V_2O_3 none; NiO none; BaO none; M_nO_3 none.

[13] W.T. = Washington's Tables; see Washington, 1917.

Digitized by Google

F. I. (II). 4 (5). 1(2). 4. Soda-trachyte, *Dómadalshraun, Torfajökull*, Iceland. Anal. M. A. Peacock. Described in thin section on p. 302.

G. "II. 4 (5). "3. 4. Trachyandesite, *Snæfellsjökull*, Iceland. Quoted from Dr. Tyrrell's as yet unpublished paper on the petrography of Jan Mayen. Anal. W. H. & F. Herdsman. Described in thin section on p. 299.

TABLE VII.

NORMS OF THE NEW ANALYSES.

	E.	F.	G.
Q	32·0	13·4	12·1
co			1·6
or	21·1	18·4	16·1
ab	39·3	52·4	33·5
an	1·1	4·7	17·8
di	1·1	5·1	
hy		2·2	14·5
wo	1·2		
mt	2·8	2·3	1·9
il	0·6	0·6	1·7
ap	0·3	0·3	0·7
H_2O	0·7	0·7	0·2
	100·2	100·1	100·1

In the main, the agreement between the norms and the modes is excellent. The analysis E. (R360, page 298) gives 32 per cent. of quartz; although not actually measured, this is about the amount modally visible. F. (R371, identical with R373, R374, page 302) shows 13·4 per cent. of normative quartz; this is not visible in the slide, and must be occult in the plentiful vitreous groundmass. This also applied to the normative quartz in G. (R325, page 299). E. gives a

Digitized by Google

normative felspar almost completely free from lime, which agrees with the optical determination. The normative felspar of F. consists of or/ab/an in the proportions of 24/70/6, corresponding closely with the R.I. determination of the actual felspars which gave pure albite for the first generation of felspars, and " orthoclase with perhaps an admixture of the soda molecule " for the later crystals. In the case of G. the agreement is perfect; the normative plagioclase is ab/an = 66/34, while R.I. determinations on small fragments by the immersion method gave a mean value of " 1·555, which corresponds with that of an andesine of composition ab/an = 60/40 "; the measurements were made on the largest crystals, *i.e.*, the first to separate, which naturally have a composition somewhat more basic than that of the average felspar in the rock. Disregarding the nature of the very subordinate femic minerals, the norm gives a true value for their massed proportion in these rocks; however, as the norm does not provide for soda entering the composition of the femic minerals in acid rocks, it does not reveal the sodic nature of the pyroxene, which was determined optically as the green, soda-bearing ægirine-augite.

The two analyses of the *Dómadalshraun* lava, III. and F., were taken respectively from the obsidian and the soda-trachyte. As would be expected, the rapidly cooled product is richer in silica and in alkalis, and poorer in the bases than the more slowly cooled facies; Bäckström's value of 1·06 per cent. for TiO_2 seems excessive, and as the writer obtained 0·29 per cent. for this constituent, which value is also in keeping with the other analyses, he regards Bäckström's figure as unreliable.

With regard to the acid pitchstones of Pre-glacial age (described on page 295 *et seq.*), none were sufficiently fresh to warrant analyses. Their phenocrystic mineral content, however, agrees closely with that of the Post-glacial lava from *Dómadalshraun*, felspars of the same composition and soda-pyroxenes occurring in the same relative proportions; they may, therefore, be regarded as glassy representatives of the same magma which produced the later rock, namely, a soda-rich acid trachyte.

Digitized by Google

VII. Palagonite-tuff and Palagonite-rock.

At the commencement of the Inter-glacial period in Iceland volcanic activity underwent a marked change; the extensive basalt flows with relatively unimportant interbedded tuffs of the Pre-glacial period give way to vast accumulations of tuff and breccia with only a negligible proportion of true lavas. On account of the prevalence of the material palagonite in those rocks they were termed collectively "Palagonitformation," and were given by Thoroddsen a late Pliocene age (Thoroddsen, 1906, pages 287 *et seq.*). Pjeturss, however, found undoubted glacial moraines in the Palagonite Formation, and for that reason he says—"Der wirklich vulkanische Teil dessen, was man früher Palagonit- oder Breccienformation nannte, sind die Ruinen quartärer Stratovulkane und Tuffkegel" (1910, page 7). As the Palagonite Formation is overlain by striated basalts, it must be regarded as Inter-glacial in age.

Iceland has become the classic locality of palagonite, and the numerous researches of the early writers are best summarised by Rosenbusch (1896, pages 1038 *et seq.*). Rosenbusch regards "Palagonit" or "Palagonitfels" as a rock name to be applied to basaltic tuffs which consist entirely or dominantly of holovitreous, or only slightly porphyritic basaltic lapilli which are bound together by a cement derived entirely, by hydrochemical action, from the glass fragments. He emphasises that palagonite is not a homogeneous substance, and that analyses of palagonite are bulk analyses of basaltic glasses with their alteration products.

In contradistinction to this use of the term palagonite, certain writers have used it in a modified mineral sense. Teall, in a study of the rocks of Franz Joseph Land (1897, page 485), writes as follows:—"Palagonite is especially abundant in the amygdaloidal varieties (of basalt), where it occurs not only wedged in between the crystalline constituents, but also as the infilling material of some of the amygdules." Emerson also uses palagonite in this sense, and describes under that name glassy areas with agate-like structure in a gabbroid diabase from the Holyoke trap sheet (1905). The present writer observed palagonite representing the vitreous residue

Digitized by Google

in a Pre-glacial basalt from *Akrafjall* (page 277), and in a coarse, intrusive rock from *Viðey* (page 285). In the latter occurrence palagonite was so prominent and characteristic a feature that he applied the name "palagonite-dolerite" to the rock.

It remains to notice a third signification of the term palagonite. The famous occurrence at *Seljadalur*, Iceland, was originally described by Bunsen as a flow of glass 80 to 100 feet thick, but is figured by Rosenbusch in his "Gesteinslehre" as a typical "palagonitfels," *i.e.*, palagonite-tuff. Emerson (loc. cit.) made a careful re-examination of this rock, and reverted to Bunsen's view that this was a case of palagonite replacing a continuous, though much cracked, glassy basaltic flow. Of the palagonitic rocks to be described, two specimens fall indubitably into this category, and an examination of a number of the Icelandic palagonite occurrences, made by Dr. Tyrrell and the writer this summer, helps greatly to strengthen this conception.

In view of the above, it seems desirable to treat the term palagonite in a manner analogous to a mineral qualifier, and there to apply *palagonite-tuff* to basaltic tuffs consisting dominantly of vitreous basaltic lapilli cemented by their own hydrochemical decomposition products, *palagonite-rock* to extrusive or intrusive, vitreous, basaltic masses which were originally coherent and are now completely or largely palagonitised, and *palagonite-basalt* and *palagonite-dolerite* respectively to basalts and dolerites which contain notable proportions of palagonite replacing a vitreous residue.

Palagonite-tuff.

R224, 225, from *Viðey*, off *Reykjavík*. Of these specimens Mackenzie says—"This rock may be considered as nondescript. It it composed principally of the brilliant black substance, small specks of which were observed in A20" (A20 = R220, a palagonite-dolerite described on page 285), "but here it occurs in larger masses, mixed with a dull blackish-green matrix, which circumstance denotes it to be a tuff. . . . The black substance seems to be pearlstone, and the rock may therefore be called a pearlstone tuff."

Digitized by Google

The black fragments, which vary in size from 1½ cm. downwards, are seen with the unaided eye to contain an occasional felspar; they have a pitch-like lustre and fracture, and in the second example a few threads of calcite are drawn through the rock. In thin section (Plate IV., Fig. 8) the rock is seen to consist of numerous glass fragments whose boundaries are smooth concave and convex curves, producing the "Bogenstruktur" of Mügge. These fragments, which occasionally contain a fresh, euhedral crystal of plagioclase or pyroxene, are in many cases traversed by flow bands; these bands are composed of numerous points of opaque mineral which doubtless represent the more ferriferous constituents of the glass. The bands may be absent, sparse, or so plentiful that they coalesce. The colour of the glass is brown in various shades, and each fragment is surrounded by a border of light yellow glass, into which the flow bands continue; the light borders are therefore the product of alteration of the darker glass. As a matrix for these fragments are seen three minerals. Firstly, a golden-yellow, sometimes slightly green, spongy or fibrous material of marked double refraction, which has a habit of growth sometimes spherulitic, sometimes lobate or "digital," and sometimes cellular. This material commences crystallisation at the bleached borders of the glass fragments, and in ordinary light often seems to merge imperceptibly into the pale glass. The remaining space is occupied by two water-clear zeolites; one appears as sparse crystals which sometimes show cubic outlines, and are quite isotropic; the other fills the remaining interspaces, shows no cleavage, and polarises faintly but distinctly, extinguishing roughly in sectors. The glass fragments contain numerous circular and elliptical steam cavities. In some of these precisely the same sequence of minerals is found; a bleached lining, a growth of the delicate, fibrous, doubly refracting mineral of digital habit, and finally the isotropic, and the faintly polarising zeolites.

R236, taken a few miles S. of *Reykjavík*, differs from the *Viðey* specimens chiefly in the relative proportions of the materials constituting it. The glass fragments are larger,

Digitized by Google

and occupy over 90 per cent. of the section. Apart from a few included crystals of plagioclase and pyroxene, the only other material present is the golden-yellow, fibrous mineral of marked double refraction, which serves to bind together the fragments of basaltic glass; in this case zeolites are entirely absent.

Palagonite-rock.

R253, from above the sulphur banks at *Krisuvík*. "It may be a variety of A24 (R244), from the appearance of specks of pearlstone"—Mackenzie.

In this case one cannot well distinguish individual glass fragments, but the specimen rather gives the impression of a continuous mass of glass, much cracked, and almost completely altered to a dull, friable material. The few minute areas of unaltered glass were recognised by Mackenzie, and as the above quotation shows, led him to regard this rock as a variant of the *Viðey* palagonite-tuff. In thin section (Plate IV., Fig. 9) the rock is seen to consist of light-brown glass free from flow banding. The glass, which contains nests of fresh plagioclase laths, and is traversed by numerous cracks filled with calcite and occasionally by a zeolite, has been altered almost completely to a yellow-brown, fibrous mineral of marked double refraction, the fibres of which extinguish at low angles (about 5°) to their length. The alteration of the glass has usually commenced at the periphery of the numerous circular and bladder-shaped cavities, and has proceeded by periodic, agate-like growth to replace the light-brown glass; sometimes the replacement seems to have commenced spontaneously with the glass, and in these cases the fibrous mineral does not assume marked radial orientation, as it does when commencing as a cavity lining, but occurs as an irregular matted mass containing a few microscopic spherulites of the same mineral. In this case alteration had proceeded almost to the limit, the relative amount of pale brown, unaltered glass, represented by the few black, vitreous specks in the hand-specimen, being very small; in this respect the area figured is not quite representative, but it was chosen because it showed well alteration

Digitized by Google

commencing around steam cavities. In the hope of throwing some light on the process of palagonitisation this specimen was subjected to analysis.

R361 from *Innrtholmur, Hvalfjörður*, is indistinguishable from R253 in the hand-specimen, and in thin section it is very similar. The section consists very largely of the yellow-brown, fibrous mineral of marked double refraction (alteration having commenced spontaneously, not as cavity lining), resulting in the matted mass with small spherulites as previously described. A few pale-brown areas of unaltered glass are present, together with a fair proportion of secondary calcite appearing as crack infillings; zeolites are absent.

TABLE VIII.

ANALYSES OF PALAGONITE.

	H.	H'.	I.	II.	III.
SiO_2	39·90	43·15	38·96	40·35	35·48
Al_2O_3	12·77	13·81	11·62	5·11*	8·30
Fe_2O_3	9·96	10·77	14·75	24·99	12·30
FeO	2·25	2·43	n.d.	3·55	14·60
MgO	6·12	6·62	6·29	5·48	7·10
CaO	8·05	3·84	9·13	1·32	1·04
Na_2O	0·64	0·69	0·68	0·18	3·92
K_2O	0·69	0·75	0·72	1·44	tr.
H_2O+	4·01	4·34	17·85	8·51	16·80
H_2O-	10·97	11·87	n.d.	8·51	n.d.
TiO_2	1·16	1·25	n.d.	0·20	none
P_2O_5	0·21	0·23	n.d.	—	n.d.
MnO	0·23	0·25	n.d.	0·22	n.d.
CO_2	3·52	—	n.d.	none	n.d.
	100·48	100·00	100·00	99·86	99·54

H. Palagonite-rock, from above the sulphur banks at *Krisuvík*, Iceland. Anal. M. A. Peacock.

H'. Analysis D. less secondary calcite; CO_2 together with a molecular equivalent of CaO have been deducted, and the remainder calculated to 100 per cent.

I. Palagonite, *Seljadalur*, Iceland. Quoted in Rosenbusch, 1898, p 407. Insol. res., 4·11 per cent. Anal. Bunsen.

Digitized by Google

II. Palagonite in gabbroid diabase, *New Reservoir, Holyoke, Massachusetts.* Sp. gr., 1·91. *With possible P_2O_5. Emerson, 1905, p. 112. Anal. George Steiger.

III. Palagonite from amygdules in basalt at *Cape Flora. Franz Joseph Land.* Newton and Teall, 1897, p. 485. Anal. Teall.

The above are the available analyses of basaltic glasses in which palagonitisation has proceeded to the utmost extent; they therefore give the nearest approach to the chemical composition of the products of palagonitisation.

Before examining the analyses it is desirable to determine, if possible, whether palagonitisation is simply a chemical readjustment of the components of an unstable basaltic glass, or whether an introduction of foreign material has been involved. The thin sections showed that the first stage of the process was invariably a bleaching of the brown glass areas; this took place in exactly the same manner around the margins of individual fragments, and around the bounding surfaces of totally enclosed cavities. The bleached areas were totally isotropic, and the fact that schlieren of ore specks, when present, invariably continued unchecked from the unaltered interior into the bleached marginal zone, proved that the bleached borders and linings were integral with the unaltered areas. The second stage, which may have been contemporaneous with the first, was marked by the growth of the golden-yellow, fibrous, doubly refracting mineral of "digital" habit; this growth commenced almost imperceptibly from the bleached zones, and again it took place marginally and as cavity lining in precisely the same way. During the third stage the remaining interspaces were filled with zeolites and calcite; it is to be observed, however, that this stage was not always represented. As the complete process of palagonitisation was observed in a totally enclosed cavity of the original glass, it would appear, assuming that the glass was impervious to travelling solutions, that this alteration process took place without the introduction of extraneous material. The fact, however, that calcite was found in one case (R253, Plate IV., Fig. 9) as the final infilling material in a totally enclosed cavity, and that

Digitized by Google

notable amounts of calcite cannot be regarded as a possible primary constituent of any but plutonic rocks, points to the conclusion that the glass with which we are here concerned is not impervious to solutions, and that therefore palagonitisation must be regarded as a chemical readjustment of the constituents of the glass, assisted in some measure by permeating solutions.

Turning now to the analyses, it will be observed that the most striking feature is the enormous and fairly constant H_2O value, which varies from 16·21 per cent. in the calcite-free version of the author's analysis to 17·85 per cent. in that of Bunsen,[14] and the problem arises: to which constituent are we to assign this high-water content? Seventeen per cent. is an average H_2O value for a zeolite, and hence the unaltered glass and the fibrous product of the second stage must also contain an average of 17 per cent. H_2O. As the author's analysis was performed on a rock in which the relative amount of unaltered glass was negligible, we must conclude that the fibrous mineral also contains about 17 per cent. of water. Until further chemical work is done it cannot be determined what proportion of this 17 per cent. H_2O was present as a primary constituent of the unaltered glass. As the ordinary, anhydrous tachylytes are characteristically crowded with separated ores and the palagonite glasses are characteristically free from them, it is probable that a notable amount of the water is of primary origin.

The analyses also show that iron is almost invariably present in a highly oxidised state; while solutions of ferrous iron (and therefore solid solutions, *i.e.*, glasses) are only faintly coloured, solutions of ferric iron are always deeply coloured, and as the unaltered glass is always pale brown, it follows that the fibrous mineral is rich in ferric iron.

Again the lime value of all the analyses is remarkably low, taking, of course, the calcite-free version of the author's analysis. Bunsen's discordant value may again be accounted for by notable amounts of calcite in his sample. As there

[14] Bunsen's figure is probably high, as he estimated H_2O by taking the loss on ignition, which procedure releases CO_2 as well as H_2O.

Digitized by Google

is no reason to believe that the original magma differed greatly in composition from an ordinary basaltic magma, it appears that palagonitisation involves the release of lime which may, or may not be fixed in situ as calcite by permeating aqueous solutions of CO_2. And, lastly, as the values for the alkalies in all the analyses, except that of Teall, are low, and as the amount of zeolites is often considerable, it appears that the growth of the fibrous mineral has resulted in the release of alkalies and alumina which have been fixed as zeolites, and that therefore the fibrous mineral is free from, or poor in alkalies. Chemical readjustments, as detailed above, must have been induced by a change of conditions, such as a change of temperature or of pressure; of these the former is by far the more likely, and the more potent.

To recapitulate, it is concluded, from a microscopical and chemical investigation, that palagonitisation is a thermo-hydrochemical process to which hydrous basaltic glasses are susceptible. It results in the growth, around margins and in cavities, of a golden-yellow mineral which contains about 17 per cent. of water, is rich in ferric iron, poor in lime, and free from, or poor in alkalies. The growth of this mineral bleaches the glass from which it grows, by the withdrawal of ferric molecules. The lime and alkalies released in the process are frequently fixed in situ by permeating solutions, as calcite and zeolites; sometimes they are carried away. In the case of palagonite occurring as a minor constituent of basalts and of dolerites, it is noteworthy that calcite is not observed, and that therefore permeating solutions have probably not acted. In these cases palagonitisation, in the author's opinion, has followed precisely the same course as induced above, with the exception that water required for the change has been supplied internally. The penultimate product in the consolidation of a hydrous magma in which cooling has been moderately rapid, and the escape of water has been restrained, is a highly hydrated glass; the final product is water itself. Thus, with the addition of heat, we have the ideal conditions to initiate palagonitisation.

Digitized by Google

VIII. Red Partings in the Pre-glacial Formation.

The thin, red, inter-basaltic partings are characteristically developed in the Pre-glacial formation of Iceland. Mackenzie, speaking of rocks similar to those to be described, says—"Under some of the slags was a substance, apparently indurated lithomarga, of the same red colour as that which forms so prominent a feature in the aspect of Giant's Causeway, and which abounds in many parts of the county of Antrim."

Thoroddsen, in his chapter on "Die Basaltformation," *i.e.*, the Pre-glacial Formation, says—"Zwischen den Basaltdecken finden sich sehr häufig dünne rote Lagen, die aus alten Schlacken, Glasstümpfchen, Zeolithen u.a.m. bestehen, und meistens nur eine geringe Mächtigkeit (½, 1, und 1½ m.) besitzen, auch sind dieselben bisweilen in roten Ton verwandelt. Diese Lagen sind wahrscheinlich gleich den Basaltdecken während derselben Ausbrüche von ausgeworfenen Schlacken und Asche gebildet worden, und rühren veilleicht zum Teil von den Schlackenkegeln der alten Krater her" (1906, page 246).

Hawkes (1916) has studied the red beds of Iceland, especially the 1000-foot section at *Boegisa*, *Eyjafjörður*, North Iceland, where there are exposed thirty-eight basalt flows, separated by red partings. He finds that it is frequently impossible to determine the original tuff or lava nature of the rock from thin sections, but the following considerations lead him to agree with Thoroddsen that in the large majority of cases the red partings are purely detrital in origin. "If the red rock represented weathered lava, investigation in the field would show a passage to crumbling and decomposing lava surfaces, but I have hardly ever seen clear evidence of this in the case of a basalt covered by a red parting" (1916, page 387). And again—"Sometimes thin bands of acid tuff are intercalated in the red partings. They may be mere streaks an inch thick. One band 2 inches thick in a parting at *Seydisfjörður* contains well-developed crystals of soda-microcline and soda-pyroxene, minerals common in Icelandic acid rocks. In such cases

Digitized by Google

where the bands are purely acid and contain no basic material, they obviously result from contemporaneous eruptions, and it is also clear that the palagonite rock above them is material blown from a distance" (1916, page 389). And finally, a journey across the modern lava desert *Ódádahraun* convinced Hawkes that the Pre-glacial red partings found their counterpart in the masses of loose volcanic sand and dust which occupy certain parts of this area.

R288 from *Akrafjall*, *Hvalfjörður*, was found separating two amygdaloid flows of the Pre-glacial mountain *Akrafjall*. Of this specimen Mackenzie says—" This fossil is very similar to red sandstone; but it is in fact a fine-grained tufa. The mass of it which we saw was not more than a foot thick, and was irregularly interposed between the beds." As this specimen does not agree fully with the rock described by Hawkes, it will be considered in some detail. In the hand-specimen it is a bright red, hard, compact rock, and, as Mackenzie says, not unlike a fine-grained sandstone. In thin section (Plate IV., Fig. 10) it is seen to consist largely of basic volcanic glass fragments of an average size of 0·1 to 0·25 mm. These are riddled by circular steam cavities, and the boundaries of the fragments themselves pass through marginal cavities, producing an embayed structure. In colour the glass fragments vary from orange-yellow, through various shades of red and brown, to opaque, the largest pieces being as a rule the lightest in shade, and the smallest ones the darkest. In addition there are numerous rounded and cloudy crystals and fragments of plagioclase (bytownite) occurring isolated, and never included in the glass. These materials are cemented by a colourless mineral, isotropic or faintly polarising, occasionally showing a cleavage, and with a refractive index just below 1·490, and therefore analcite. This mineral also occasionally occurs in the steam cavities of the glass fragments; these, however, are usually empty, and the glass surrounding them is frequently a shade lighter, closely resembling the light borders found around the glass areas of the palagonite-tuff from *Viðey* (page 309). There can be no doubt that this rock is a tuff, and not the product of the weathering of a lava surface in situ; the fact that it

Digitized by Google

is much harder and more compact than Hawkes' partings, which he describes as "soft, colloidal rock," is perhaps accounted for by Mackenzie's observation—"The mass of it which we saw was not more than a foot thick." Such a thin parting would naturally suffer greater induration from the succeeding lava flow than the normal partings which, according to Thoroddsen, reach a thickness of 7 feet. Further, the æolian mode of formation suggested by Hawkes fully suits the present case; the rounded, weathered felspars strongly suggest transportation by wind, while the irregular nature of the band could well be accounted for by accumulation of volcanic dust in variable surface depressions.

R299, from the same locality, was taken higher up the mountain. Mackenzie says—"Is similar to B10 (R288), and, being coarser, serves to elucidate the nature of that substance." In the hand-specimen it is coarser, of a duller red colour and more friable than R288. In thin section it closely resembles that rock. The majority of the glassy fragments are composed of nearly opaque tachylyte, the remainder are chocolate brown and translucent. The inter-space-filling analcite shows good cubic cleavages, and steam cavities in the glass fragments are frequently filled with radial isotropic growths of the same mineral.

R363 from *Egilstadir*, R. Þjorsá, ". . . is the same with B10 (R288) from the mountain of Akkrefell (*Akrafjall*). It is here connected in the same way with submarine lava" [15] —Mackenzie. This tuff, from the small Pre-glacial inlier at *Egilstadir* on the R. Þjorsá, so closely resembles R299 from *Akrafjall*, and the overlying amygdaloids from both areas are so alike, that it is probable that they belong to the same horizon.

[15]By "submarine lava" Mackenzie means amygdaloid. Recognising the igneous origin of the amygdaloidal basalts, and realising that the contained calcite and zeolites could not have crystallised from the molten condition at atmospheric pressure, Mackenzie concluded that basalts containing these minerals must have been erupted on the sea-floor at such a depth that the prevailing pressure was sufficient to prevent the dissociation of the minerals in question. The possibility of calcite and zeolites being secondary minerals deposited from aqueous solution never occurred to Mackenzie, as this was an odious Wernerian conception.

Digitized by Google

IX. Agglomerates.

R233. "Tufa found a few miles south of *Reykjavík*, on the seashore. It contains masses of greenstone, basalt, amygdaloid, and small specks of the substance forming so large a proportion of A24 (black pearlstone)"—Mackenzie A24 = R224, the *Viðey* palagonite-tuff, page 309.

The hand-specimen shows only fragments of basalt and glass in a fine-grained matrix; the "greenstone" and amygdaloid fragments were doubtless observed in larger masses in the field. The basalt fragments belong to the ophitic variety which occupies a large area around *Reykjavík*, and is described elsewhere (page 282). Along with these are seen smaller, yellow-brown, unaltered glass fragments (Mackenzie's "black pearlstone") which are probably the vitreous facies of the same magma which produced the ophitic basalt, and which also agree completely with the unaltered glassy areas of the *Viðey* palagonite-tuff. The matrix for these rock and glass fragments consists of smaller pieces of basalt, smaller glass fragments often containing fresh, euhedral olivine, pyroxene and plagioclase crystals, fragments of these minerals, and glass dust. The glass in this rock is always fresh, totally isotropic, and free from alteration.

R234. "From an included mass in the (above) tufa"—Mackenzie. The rock is a much altered banded pitchstone probably transported by ice from one of the many areas of the older acid intrusives; it has adhering to it some tuff matrix identical with that of R233.

R235 from the same place "appears to be a wacke much indurated"—Mackenzie. It is free from large fragments and corresponds with the matrix of R233. The smaller fragments have turned a bright yellow, without, however, becoming doubly refracting. R209 and R237 from the same locality are rocks similar to the above, being composed of minute fragments of the minerals which constitute the ophitic basalt flows between which they are bedded.

Digitized by Google

R244, from near *Keflavik, Gullbringu Sysla.* "Tufa . . . inclosing round, black, vitreous masses like obsidian, perhaps black pearlstone"—Mackenzie. The thin section shows that the "round, black, vitreous masses" are lapilli of the same ophitic basalt, but showing evidence of having been ejected at an earlier stage of crystallisation. The lapilli consist of an earlier stage of crystallisation. The lapilli consist of yellow-brown glass in which aggregates of fresh olivine crystals have developed. Around the vitreous lapilli a very little yellow palagonite has developed, while the matrix consists of a dull brown clay; this rock may be a conglomerate, but field evidence is lacking.

R252, near the *Kaldá, Gullbringu Sysla.* This locality lies near a junction between the Post-glacial basalts and the older ophitic basalts. The agglomerate contains lapilli of a fine-grained, olivine-free basalt, which is similar to basalts described from other Post-glacial localities; and also a few fragments of the vitreous facies of the ophitic lava. The matrix is again composed of crystals and fragments of felspar, pyroxene, and olivine, together with some altered glass.

R341, near *Bulandshöfdi, Snæfellsnes Sysla.* This specimen shows greatly altered rock fragments bedded in a matrix of green earth; the latter scratches readily with the finger-nail, and the powder has an unctuous feel, in which respects it is similar to the palagonite described by Teall (1879, page 485), but cannot be classed as such as it is attacked only slowly by strong hydrochloric acid, while palagonite is rapidly decomposed even by weak acid. The contained rock fragments are frequently indeterminate, the only recognisable being felspar, which is almost completely pseudo-morphed in calcite. A few fragments of a spherulitic rhyolite are recognisable.

R281, *Baula, Myra Sysla. Baula* is one of the many scattered localities of the older acid rocks. The hand-specimen shows dark lapilli bedded in a compact, light-grey matrix. The thin section reveals fragments of a vitreous rhyolite without phenocrysts, bound by a matrix of the same material finely comminuted.

Digitized by Google

X. Mineralogical and Chemical Characteristics of the Icelandic Igneous Rocks.

Quartz.—Only in three thin sections, the rhyolite from *Baula* (page 298), and the spherulitic pitchstones R355, 287, pages 297 and 298 respectively, was quartz determined with certainty, and in notable amount. In the calculated mineral content of the *Baula* rock it constituted 32·0 per cent. of the rock, which was approximately the amount actually seen. Normative quartz, grading in amount from 32·0 per cent. in the above rock to 6·78 per cent. in the Pre-glacial basalt from *Akrafjall* (page 277), but occult in thin section, was found by calculation in all the rocks analysed, with the exception of the unsaturated olivine-basalts of Inter- and Post-glacial age.

Felspathoids.—These were never observed in the thin sections; calculations, however, indicated quantities of nepheline up to 3·41 per cent. in the chrysophyric picrite-basalt from *Grindavík* (page 288), and in the ophitic olivine-basalt from *Keflavík* (page 282). The absence of marked alkalic types has been emphasised by previous writers, and the present investigation serves to confirm the assertion. A distinct sub-alkalic tendency, however, is noticed among the acid and sub-acid types, resulting in richly alkalic felspars and pyroxenes.

Felspars.—The complete range was found from almost pure alkali-felspar in the *Baula* rhyolite (or/ab/an = 21·1/39·3/1·1), to almost pure lime-felspar in the *Grindavík* chrysophyric picrite-basalt (or/ab/an = 0·8/3·7/34·2). A marked preponderance of soda over potash is everywhere noticeable; the felspar phenocrysts of the soda-trachyte from the *Dómadalshraun* were determined by refractive index as albite and anorthoclase, while the average calculated felspar had the composition or/ab/an = 18·4/52·4/4·7. Indeed, orthoclase appears to be distinctly rare, and when it does appear it is associated with more abundant anorthoclase.

Micas and Amphiboles.—These appear to be extremely rare; in a soda-trachyte from *Snæfellsjökull* (page 299), biotite flakes were recorded as accessories in a fluidal groundmass, while in a trachyandesite from the same locality a

Digitized by Google

sparse accessory mineral was described as "a brown, altered amphibole."

Pyroxenes.—Common, brown augite is found as large plates, crowded with felspars, in the Inter-glacial, ophitic basalts; in the Pre-glacial basalts it is always intergranular. Examples of augite-porphyry, to which Pjeturss refers, were not found in the collection. Among the acid rocks, green, pleochroic ægirine-augite, the soda-bearing pyroxene, is abundant and highly characteristic. It is found as small, sometimes euhedral phenocrysts in the Post-glacial soda-trachyte of the *Dómadalshraun* (page 302), and also in the Pre-glacial intrusive pitchstones (page 293). Even in the basalts the pyroxene assumes a greenish tinge at times, indicating a slight accession of the soda molecule; this was recorded of the Pre-glacial basalts of *Akrafjall* (page 277) and *Egilstadir* (page 280). Distinctly purplish pyroxene was never observed, although the titania content of the Icelandic basalts is consistently high. Occasionally, while the titania value obtained by analysis was high, no skeletal tendency was noticeable in the ores, and hence it would appear that notable amounts of titania may be contained in the pyroxene without its presence being suspected under the microscope. Lastly, augite was observed as a reaction-product, having been formed by the reaction of early formed olivine with free silica in the magma.

Olivine.—This mineral was found as macrophenocrysts only in the Inter-glacial, ophitic basalts, and in some of the Post-glacial basalts. In these rocks it tends to euhedrism, and is characteristically free from alteration. In the Pre-glacial basalt olivine was determined as a few minute, ill-defined areas which suggested strongly that they were the relics of larger olivines which had been almost completely pyroxenated by the adsorption of silica.

Ores.—Magnetite, probably never uncontaminated by ilmenite, is invariably present in the Icelandic rocks. As almost perfect cubes it is found in clusters, associated with green pyroxene, in the *Dómadalshraun* soda-trachyte. More frequently, with the accession of notable proportions of ilmenite, black ores assume well-marked acicular or skeletal

Digitized by Google

habits; this is well exemplified in the palagonite-dolerite from *Viðey* (Plate III., Fig. 4).

Apatite.—Although apatite, as calculated from the value of phosphoric anhydride, averages about 1 per cent. in the basalts, and reaches 2·35 per cent. in the trachybasalt from *Raudimelur* (page 291), the writer did not observe it in the thin sections. Dr. Tyrrell has noticed the same anomaly in the study of a collection from Jan Mayen; Holmes, on the other hand, records apatite needles and blebs in the felspars of an olivine-free basalt from *Holmatindur* (1916, page 192).

Glass.—Perfectly fresh glass constitutes the bulk of the phyric obsidian from the *Dómadalshraun* and the *Baula* pitchstones (page 294). In the Pre-glacial acid rocks fresh glass is often interbanded with cryptocrystalline zones and is typically spherulitised (Plate IV., Fig. 6).

Palagonite.—Basaltic glasses are invariably palagonitised, and the presence of palagonite in tuffs, as the main constitutent of originally coherent, vitreous basaltic bodies, and as the replacement material of the vitreous residue of basalts and dolerites, is highly characteristic of Icelandic rocks.

Calcite and Zeolites.—These are found as secondary minerals in amygdaloidal basalts, and as the end-product of palagonitisation in palagonite-tuffs; both isotropic and faintly polarising zeolites were observed, but as they were present only in microscopic amounts, exact determinations were not feasible. Analcite was determined in the thin red partings (page 317).

XI. Two Distinct Volcanic Periods in Iceland.

Geological Evidence of a Prolonged Period of Volcanic Rest During the Pliocene.

It has become usual to prefix any account of the geology of Iceland by the statement that the country consists almost entirely of volcanic rocks. Pjeturss has always striven against this conception, and his view of the importance of sediments in Iceland is best expressed in his own words—"Schätzt man die Mächtigkeit der Basaltformation auf etwa 4000 m., entfallen von dieser Gesamtmächtigkeit auf die

Digitized by Google

sedimentären Einschaltungen nicht veil weniger als 1000 m." (1910, page 3). At *Tjörnes*, in N. Iceland, there are preserved Pliocene fossiliferous deposits hundreds of meters thick; although there is perhaps a little basalt in the lowermost part, and a little volcanic ash interbedded here and there, the formation, at least in that locality, indicates a period of quiet sedimentation almost uninterrupted by volcanic activity. Pjeturss thinks it highly improbable that notable sedimentation in the Pliocene was restricted to this area; he considers it much more likely that the once widespread deposits have elsewhere been destroyed during the post-Pliocene uplift of 200 m. (*ibid.*, page 17).

Geological Evidence of the Continuity of the Inter- and Post-glacial Volcanic Periods.

Although the Inter-glacial and Post-glacial periods are characterised by distinct volcanic products, there is no evidence of volcanic discontinuity. Manifestations of Post-glacial activity are strictly confined to the territory of the Inter-glacial Formation, *i.e.*, the volcanic part of the Palagonite Formation and the striated, ophitic basalts. On a journey from *Reykjavík*, which is situated on the late Inter-glacial striated, ophitic basalts, to *Þingvellir*, which lies on early Post-glacial, unscratched basalts, one is impressed by the continuity and structural similarity of the lavas over the whole route. In the great gaping fissures at *Þingvellir* the structure of the Post-glacial lavas is beautifully revealed. It consists of numerous, successive flows of the "*helluhraun*" type, in which the surface of each flow is composed of the convex surfaces of a series of flat, interpenetrating domes. Internally, a dome is seen to consist of a surface-layer of small, rude columns, whose long axes lie normal to the surface of a dome, while the interior is traversed by a system of roughly radial joint-planes producing a core of large blocks approximating to wedge-shape. Sections of the Inter-glacial basalts in the neighbourhood of *Reykjavík* have a structure exactly similar to the "*helluhraun*" cores just described; the surface-layer of small, radial columns, however, is missing, weathering and ice transportation doubtless accounting for its removal.

Digitized by Google

The geological evidence therefore points to two great continuous periods of volcanic activity in Iceland, the Pre-glacial and the Inter- and Post-glacial, which were separated by a prolonged interval of quiescence during the Pliocene.

Petrographic Evidence in Favour of Two Distinct Volcanic Periods in Iceland.

The chemical data in a petrographic investigation of an igneous area which embraces a suite of rocks of differing composition are usually best collated in some form of variation diagram. In such a diagram the percentages of oxides, as obtained by analysis, are plotted against the silica content, or against the number of molecules of SiO_2 which are in excess or in defect of the number required to form fully saturated minerals with the remaining oxides, or against the total percentage of calculated salic minerals. Of these three methods the second was chosen, the degree of oversaturation or of undersaturation with respect of silica being regarded as the fundamental criterion.

The analyses now available range from a very acid "liparite" with a calculated excess of silica of 874 molecules, to an ultrabasic olivine-basalt which is deficient to the extent of 282 molecules of silica. In a trial diagram serious discrepancies were at once revealed in the neighbourhood of the mildly oversaturated rocks; the points obtained from the Post-glacial trachybasalt and soda-trachyte were often far removed from those obtained from the Pre-glacial average basalt and trachyandesite, although in degree of oversaturation these pairs of rocks were respectively comparable. It was then thought to plot the Pre-glacial and the Inter- and Post-glacial rocks separately and on one diagram, and the result is seen in Fig. 21. All the available analyses are not graphically represented; when more than one analysis of a particular rock type was available, either a typical one was selected, as in the case of the Inter-glacial ophitic basalt, or an average was struck between two closely according analyses, as was done with the Pre-glacial basalts. Especial care was taken to represent the extreme range of composition in each of the two series. The curves joining

Digitized by Google

the Pre-glacial percentages are drawn in full lines, while the Inter- and Post-glacial values are joined by chain-dotted lines; in all cases the curves run through all the points, no smoothing being necessary.

In the introduction it was indicated that the older igneous rocks would probably be found to differ systematically from the younger ones, and a glance at the variation diagram

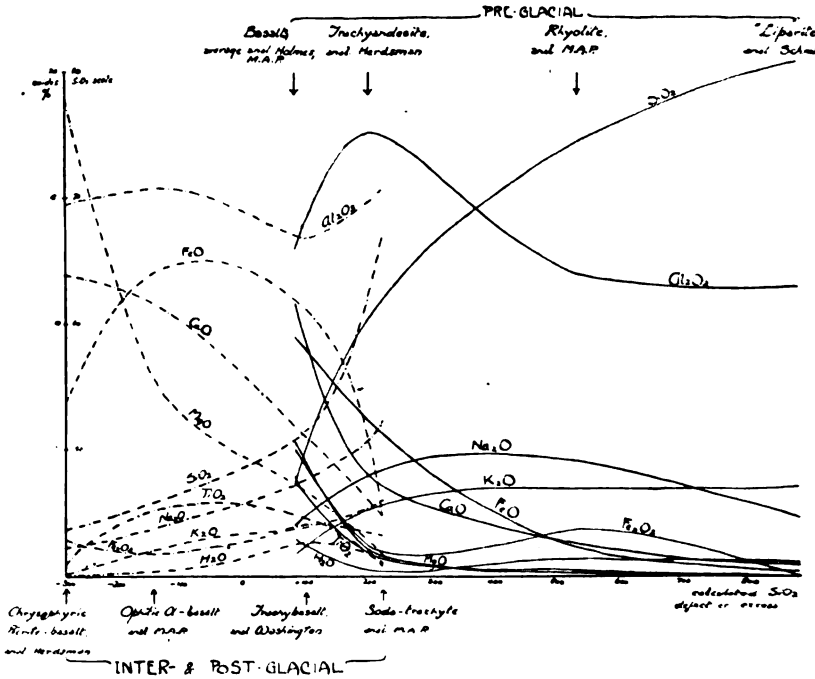


Fig. 21.—Variation Diagram of the Icelandic Igneous Suite.

at once confirms this conjecture. A vertical line drawn through zero on the " calculated SiO_2 excess or defect " axis provides the boundary between oversaturated and undersaturated rocks, and whereas the Pre-glacial analyses lie wholly in the oversaturated area, the younger rocks range from mild oversaturation to marked undersaturation. This, then, appears to provide a basic distinction between the Pre-glacial and the Inter- and Post-glacial series.

Digitized by Google

Considering, firstly, the Pre-glacial series it will be observed that decreasing SiO_2 is accompanied by increasing FeO, CaO, MgO, and TiO_2; these four constituents therefore vary systematically, and are present in that order of abundance. In the case of FeO and CaO, however, there is an exception, the CaO curve lying above the FeO curve at the acid end of the series, the inversion taking place in the neighbourhood of 73 per cent. SiO_2; the peculiar re-crossing of the curves in the region of the basalts is due to the large amount of ferric iron in the author's analysis detracting from the FeO value. It is noteworthy that towards the basic end of the diagram SiO_2 falls precipitately, while the four antipathetic constituents mentioned rise steeply; this seems to indicate that a natural limit of differentiation is being approached. The alkalies first rise gently with decreasing SiO_2, and then fall away abruptly in the basalts; a maximum is reached at about 70 per cent. of SiO_2. Soda preponderates over potash except in the very acid liparite. The alkali curves cut the lime curve at a mean position corresponding to 62 per cent. of SiO_2; this is exactly the value which Holmes obtained for the point of intersection of the lime and alkali curves in a diagram he constructed linking up Dr. Harwood's analyses of two Icelandic basalts with Bäckström's analyses of the acid rocks (1916, page 198). As Holmes points out, this feature is characteristic of "calc-alkali" series such as those of the Pacific belt. Marked sympathy is seen between Fe_2O_3 and H_2O; this sympathy may be due to magmatic H_2O acting as an oxidising agent. The high value for these constituents in the basalts is explained by the writer's specimen containing some palagonitised vitreous residue which has previously been shown to contain large amounts of H_2O and Fe_2O_3.

Turning now to the Inter- and Post-glacial series we find different relations existing between the constituents. With decreasing SiO_2 we observe an initially mutually sympathetic rise of FeO, CaO, MgO, and TiO_2, which are again at first present in that order of abundance; towards the basic end of the series these four oxides pair off, FeO and TiO_2 falling off abruptly, the change taking place approximately at the

Digitized by Google

saturation boundary, while MgO and CaO continue to increase, MgO finally far outstripping CaO. The alkalies vary consistently with SiO_2; soda preponderates over potash to an even greater extent than in the Pre-glacial series, potash practically vanishing at the basic end. The total amount of alkalies is also notably greater in the younger series, and the alkali curves cut the lime curve at an average position corresponding to 54 per cent. of SiO_2; this value is considerably lower than the corresponding value in the Pre-glacial series, and therefore, although the younger series may not be designated as typically alkalic, it shows distinct mildly alkalic tendencies. Thus, while both Hawkes [16] and Holmes (1916, page 199) (the former speaking only of the acid rocks) regard the Icelandic suite as sharing the characters of a " calc-alkali " series and of an " alkali " series, the writer would rather say that the suite is composite, its divisibility being supported both by geological and by petrographic evidence, and that it consists of a Pre-glacial " calc-alkali " series, and an Inter- and Post-glacial series of mildly alkalic charcter.

Pjeturss, in remarking on the absence of known volcanoes in the Pre-glacial country, makes the following conjecture:— " Vielleicht ist dies so zu erklären, dass in Tertiär die Magmaherde in weit geringerer Tiefe lagen, und dass das Magma überall mit nahezu gleicher Leichtigkeit den Weg zur Oberfläche finden konnte, während im Quartär die Magmaherde mehr lokalisiert waren und teifer lagen " (1910, page 18). With the magma sources near the surface one would expect products of differentiation of a less advanced type than those derived from deep-seated, localised sources; and that differentiation has proceeded to a greater degree in the younger series is precisely the impression conveyed by the variation diagram.

XII. Summary and Acknowledgments.

A comprehensive suite of Icelandic igneous rocks has been subjected to detailed microscopical and chemical investigation; the specimens have been described on a classificatory

[16] Hawkes, L. Norsk Geol. Tidsskrift, vol. iv. (1), p. 42, Kristiania, 1916.

Digitized by Google

basis, depending both on geological age and on composition. In addition to the usual optical methods, the immersion method for finding the mean refractive index has always been applied in the determination of felspars.

Whereas up to recently all Icelandic lavas have been covered by the terms " basalt " and " liparite," the collection was found to contain many specimens of intermediate and extreme composition, which made desirable the use of more narrowly defined rock names.

To the pre-existing small number of reliable analyses eight new and complete analyses have been added; five of these were conducted by the writer, the limits of error stipulated by Hillebrand being observed. The mineral contents, as calculated from the new analyses, were compared with the respective actual mineral contents observed. Numerous cases of excellent parallelism were recorded; several cases of the analyses revealing unsuspected quantities of certain constituents were observed; and a few instances were noted in which the theoretical allocation of the oxides produced minerals differing slightly from those actually observed.

In a set of specimens of varying texture, taken from the Inter-glacial ophitic basalts, it was observed that the amount of olivine present bore a direct relationship to the rate of cooling, and could therefore not be regarded as of basic, classificatory value; an explanation was sought in Bowen's Reaction Principle.

In a series of Pre-glacial, spherulitic rhyolites the initiation of secondary, ferruginous spherulites was explained by analogy with the segregation of the iron-bearing minerals in the Post-glacial acid flows.

In the section devoted to the palagonite-bearing rocks certain recommendations were made regarding nomenclature; after discussing the microscopical and chemical data the writer expressed the view that palagonitisation is a thermo-hydrochemical process to which hydrous basaltic glasses are susceptible, and that it involves the growth of a yellow, fibrous mineral which contains about 17 per cent. of water, is rich in ferric iron, poor in lime, and free from, or poor in, alkalies.

Digitized by Google

An examination of specimens of the thin, red, inter-basaltic tuff partings confirmed Hawkes' theory of æolian accumulation.

The available chemical data was collated in the form of a variation diagram which shows that the Icelandic suite falls naturally into two series, a Pre-glacial series and an Inter- and Post-glacial series which correspond to two well-defined volcanic periods. The Pre-glacial series is a "calc-alkali" series, and lies wholly in the oversaturated range, while the Inter- and Post-glacial series has mildly alkalic characters, and extends on both sides of the saturation boundary.

This work was conducted during the tenure of a Carnegie Research Scholarship, and in conclusion the writer wishes to convey to Dr. G. W. Tyrrell, his supervisor, his great appreciation of Dr. Tyrrell's ever-ready, expert guidance. He is also indebted to Professor G. G. Henderson for providing every facility for performing the chemical analyses.

XIII. REFERENCES.

Bäckström, H.
1891. "Beiträge zur Kentniss der isländischen Lipariten."—*Geol. Fören. i Stockholm Förhandl.*, xiii., pp. 637-682.

Bailey, E. B.
1919. "Iceland—A Stepping Stone."—*Geol. Mag.* (vi.), vi., pp. 466-447.

Bowen, N. L.
1922. "The Reaction Principle in Petrogenesis."—*Jour. Geol.*, xxx., pp. 177-198, fig. 5.

Emerson, B. K.
1905. "Plumose Diabase and Palagonite from the Holyoke Trap Sheet."—*Bull. Geol. Soc. Amer.*, xvi., pp. 91-130, pls. xxiv.-xxxii.

Hawkes, L.
1916. "The Building up of the North Atlantic Volcanic Plateau."—*Geol. Mag.*, (vi.), iii., pp. 385-395, pl. xvi.

Holmes, A.
1918. "The Basaltic Rocks of the Arctic Region, with Analyses by H. F. Harwood."—*Min. Mag.*, xviii., pp. 180-223, pls. vi.-vii.

Holmes, A.
1920. "The Nomenclature of Petrology" (London).

Digitized by Google

Lacroix, A.
1923. "Comparaison de la Composition chimique de deux Laves d'Islande, caractérisant des Éruptions dont le Mode de Dynamisme est différent."—*Comptes rendus*, (Paris), t. 177, pp. 369-373.

Mackenzie, Sir G. S.
1811. "Travels in Iceland during the Summer of the year 1810" (Edinburgh), p. 491, with map.

Penck, A.
1879. "Ueber Palagonit-und Basalttuffe."—*Zeitschr. Deutsch. Geol. Gesellsch.*, xxxi., pp. 504-577.

Pjeturss, H.
1900. "The Glacial Palagonite-Formation of Iceland."—*Scott. Geog. Mag.*, xvi., pp. 265-293.
1910. "Island."—*Handbuch der regionalen Geologie*, iv., Abth. i., p. 22.

Rosenbusch, H.
1896. "Mikroskopische Physiographie der Massigen Gesteine" (Stuttgart), 1896.—*II, Massige Gesteine*, pp. xiv. + 1360, pl. vi.
1910. "Elemente der Gesteinslehre."—3rd ed. (Stuttgart), 1910, pp. viii. + 692, fig. 107, pl. ii.

Schmidt, C. W.
1885. "Die Liparite Islands in geologischer und petrographischer Beziehung."—*Zeitschr. Deutsch. Geol. Gesellsch.*, xxxvii., pp. 737-791, pls. xxx.-xxxiii.

Teall, J. J. H., and Newton, E. T.
1897. "Notes on a Collection of Rocks and Fossils from Franz Joseph Land, made by the Jackson-Harmsworth Expedition during 1894-1896."—*Quart. Journ. Geol. Soc.*, liii., pp. 477-518, pls. xxxvii.-xli.

Thoroddsen, Th.
1891. "Om Nogle postglaciale liparitiske Lavaströmme i Island."—*Geol. Fören. i Stockholm Förhandl.*, xiii., pp. 609-620, fig. 2.
1901. "Geological Map of Iceland, surveyed in the years 1881-1898, edited by the Carlsberg Fund (Copenhagen), scale1 : 600,000."
1905-6. "Island, Grundriss der Geographie und Geologie."—*Peterm. Geogr. Mitth.*, Ergänz., cli.-cliii., p. 358, fig. 16, pl. iii., maps 4.

Washington, H. S.
1917. "Chemical Analyses of Igneous Rocks published from 1884 to 1913, inclusive, with a critical discussion of the character and uses of analyses."—*U.S. Geol. Surv.*, Prof. Paper 99, p. 1201.
1922. "Deccan Traps and other Plateau Basalts."—*Bull. Geol. Soc. Amer.*, xxxiii., pp. 765-804.
1923. "Petrology of the Hawaiian Islands."—*Amer. Journ. Sci.* (v.), v., pp. 465-502.

Wright, F. E.
1915. "Obsidian from Hraftinnuhryggur, Iceland: its Lythophysae and Surface Markings."—*Bull. Geol. Soc. Amer.*, xxvi., pp. 255-286, fig. 12.

Digitized by Google

XIV. EXPLANATION OF THE PLATES.

Plate III.

Fig. 1.—Palagonite-basalt (R284), of Pre-glacial age, *Akrafjall, Hvalfjörður*, ordinary light, ×25. Described in thin-section on p. 277; analysis on p. 280.
a-Bytownite,
b-Labradorite,
c-Augite,
d-Ore,
e-Palagonite.

Fig. 2.—Basalt (R317), of Pre-glacial age, *Stapi, Snæfellsnes*, I., ordinary light, ×25; II, ordinary light, ×160. Described in thin-section on p. 278.
a-Bytownite,
b-Labradorite,
c-Augite,
d-Ore,
e-Olivine.

Fig. 3.—Ophitic olivine-basalt (R260), *Keflavík, Gullbringu Sysla*, ordinary light, ×25. Described in thin-section on p. 282; analysis on p. 286.
a-Labradorite,
b-Augite,
c-Olivine,
d-Titaniferous ore.

Fig. 4.—Palagonite-dolerite (R220), age uncertain, *Viðey*, off *Reykjavík*, ordinary light, ×25. Described in thin-section on p. 285.
a-Labradorite,
b-Augite,
c-Ilmenite,
d-Palagonite with agate structure.

Fig. 5.—Chrysophyric picrite-basalt (R258), of Post-glacial age, *Grindavík, Gullbringu Sysla*, ordinary light, ×25. Described in thin-section on p. 288; analysis on p. 290.
a-Olivine,
b-Calcic bytownite,
c-Sub-ophitic groundmass of augite and labradorite.

Plate IV.

Fig. 6.—Spherulitised pitchstone (R352), of Pre-glacial age, *Drapuhlidarfjall*, polarised light, ×25. Described in thin-section on p. 295.
a-Radial, felspathic spherulite,
b-Concentric, ferruginous spherulite.

Fig. 7.—Soda-trachyte (R374), of Post-glacial age, *Dómadalshraun, Torfajökull*, ordinary light, ×25. Described in thin-section on p. 302; analysis on p. 305.
a-Albite,
b-Soda-microcline,
c-Aegirine-augite,
d-Magnetite.

Digitized by Google

Fig. 8.—Palagonite-tuff (R225), *Viðey*, off *Reykjavík*, ordinary light, × 160. Described in thin-section on p. 309.
a-Hydrous, basaltic lapilli, with schlieren of separated ore,
b-Bleached borders,
c-Fibrous, hydrated mineral of "digital" habit,
d-Zeolites.

Fig. 9.—Palagonite-rock (R253), from above the sulphur banks at *Krísuvík*, ordinary light, × 25. Described in thin-section on p. 311; analysis on p. 312.
a-Hydrous, basaltic glass, originally coherent,
b-Growth of the fibrous, hydrated mineral as a cavity lining,
c-The fibrous, hydrated mineral largely replacing the original glass,
d-Calcite,
e-Nest of felspar laths.

Fig. 10.—Thin, red, interbasaltic tuff parting (R288), of Pre-glacial age, *Akrafjall*, *Hvalfjörður*, ordinary light, × 40. Described in thin-section on p. 317.
a-Vitreous, vesicular, basaltic ejecta,
b-Isolated, wind-rounded crystals of bytownite,
c-Cementing analcite.

Digitized by Google

PROCEEDINGS OF THE GEOLOGICAL SOCIETY OF GLASGOW.

SESSION 1922-1924.

(Sixty-fifth to Sixty-seventh Session.)

---

207 BATH STREET, GLASGOW, 12TH OCTOBER, 1922.

The first meeting of the sixty-fifth Session was held in the Rooms—Mr. MACNAIR in the chair. An exhibition of lantern slides of local geology was given by the President, Mr. MACNAIR.

P. MACNAIR.

207 BATH STREET, GLASGOW, 9TH NOVEMBER, 1922

Second meeting of the Session—Mr. MACNAIR in the chair. Mr. W. H. HERDSMAN read a paper on "Problems of Ore Genesis." He is of opinion that subsidences of the ocean floor produce sudden blows on the crust, which cause fusion of the overlying rocks. He preferred the other theory of the sedimentary origin of ore deposits, notably Pyrites, in place of the more modern igneous theory.

R. W. DRON.

---

207 BATH STREET, GLASGOW, 14TH DECEMBER, 1922.

Third meeting of the Session—Prof. R. W. DRON in the chair. Mr. MARTIN PEACOCK, B.Sc., read a paper on "Icelandic Geology." [*See present Volume.*]

DONALD PATTON.

---

207 BATH STREET, GLASGOW, 11TH JANUARY, 1923.

Fourth meeting of the Session was held in the Botany Lecture Room, the University—Mr. G. W. TYRRELL in the chair. Prof. J. W. GREGORY, F.R.S., delivered a lecture on his recent journey in Chinese Tibet. [*See his published work,* "To the Alps of Chinese Tibet." Seeley, Service & Co.]

DONALD PATTON.

Digitized by Google

207 BATH STREET, GLASGOW, 8TH FEBRUARY, 1923.

Fifth meeting of the Session—Mr. DONALD PATTON in the chair. Mr. TYRRELL exhibited a glaciated stone, brought by Sir Martin Conway from Horn Sound, showing very regular wavy lines incised on its surface. Dr. W. R. SMELLIE exhibited and read a paper on chipped flints from Iraq. They were found at a camping-place called Maher-ton, which name means House of Craft. Pieces of bottle glass, chipped in the same manner by natives of N. Australia, were shown by Mr. H. R. J. CONACHER. Mr. ROBERTS said that flints of this kind were common in Northampton. Mr. Stark, in Burma, had seen heat used to split flakes of jade.

P. MACNAIR.

207 BATH STREET, GLASGOW, 8TH MARCH, 1923.

Sixth meeting—Mr. P. MACNAIR in the chair. The President gave an address on "Recent Theories of the Structure of the S.W. Highlands." An exhibit of micro-sections from the Christie collection of Crypto-crystalline forms of Silica was projected with the lantern microscope by Mr. JAS. HOLMES, and described by Mr. TYRRELL.

P. MACNAIR.

207 BATH STREET, GLASGOW, 12TH APRIL, 1923.

Seventh meeting—Mr. MACNAIR in the chair. A paper was read by Mr. ECKFORD and Mr. MANSON, officers of the Geological Survey, on "Glacial Phenomena in the Galashiels District." They described dry channels and gravel terraces, formed during the later stages of the ice retreat. Channels at Bluecairn and Threepwood seem to be results of overflow from a lake held in that area by ice lying in the lower tracts of the Allan Water. The overflow at Bluecairn leads to the Leader at 827 feet. The second escape is near Threepwood. The final drainage took place by the Lauder Burn. The terraces are 50 feet above stream level, and the gravels are derived chiefly from the Boulder Clay. Professor GREGORY remarked on the proof that this paper gave that these glaciers came from the S. Uplands.

P. MACNAIR.

207 BATH STREET, GLASGOW, 11TH OCTOBER, 1923.

The first meeting of the sixty-ninth Session—Mr. MACNAIR in the chair. The President, Mr. MACNAIR, delivered the second part of his presidential address on "The Physical Conditions under which the Deutozoic Rocks were deposited."

J. G. ROBERTS.

Digitized by Google

207 BATH STREET, GLASGOW, 8TH NOVEMBER, 1923.

The second meeting of the Session—Mr. J. G. ROBERTS in the chair. The following office-bearers were elected:—

President—Dr. G. W. Tyrrell.

Vice-President—Mr. J. G. Roberts.

Hon. Secretary—Mr. John Weir, M.A.

Members of Council—Miss Ethel Currie, M.A., B.Sc.; Mr. Duncan M'Vean, B.Sc.; Mr. Arthur Shute; Mr. James Holmes.

A letter was read from Mr. James Neilson offering a gift of books to the Society's Library. A paper by Mr. James Stark was read by Mr. Duncanson on the "Red Sandstone of Toward." [*See this Volume.*] Fossils from the Mokattam Limestone, near Cairo, were exhibited by Mr. Stark.

GEOLOGY DEPARTMENT, GLASGOW UNIVERSITY, 13TH DECEMBER, 1923.

The third meeting of the sixty-sixth Session. Members were present at the invitation of the Glasgow University Geological and Zoological Societies to hear a lecture by Prof. GRAHAM KERR, F.R.S., on "Animal Morphology."

G. W. TYRRELL.

---

207 BATH STREET, GLASGOW, 10TH JANUARY, 1924.

The fourth meeting of the sixty-sixth Session—*President*, Dr. W. G. TYRRELL in the chair.

Mr. D. B. DUNCANSON introduced a discussion on "Recent Theories of Crustal Movement." Mr. Duncanson gave a comprehensive summary of Prof. Joly's theory, and an interesting general discussion ensued.

J. G. ROBERTS.

---

207 BATH STREET, GLASGOW, 14TH FEBRUARY, 1924.

The fifth meeting of the sixty-sixth Session—Mr. J. G ROBERTS in the chair.

The President, Dr. G. W. TYRRELL, delivered a lecture on "The Geology of the North Atlantic." Dr. Tyrrell defined the extent of the North Atlantic, described its configuration and wedge-shaped contours, and discussed the geological frame in which it is set, emphasising the element of symmetry in the structure of its east and west sides, and the trans-polar strike of the Caledonian folding. The lecturer briefly surveyed the main occurrences and petrographic characters of the Kainozoic igneous episode, as illustrated by the North Atlantic islands, and by dredgings of the Rockall and Porcupine banks. Slides were exhibited showing characteristic occurrences and structures.

Digitized by Google

Dr. TYRRELL summarised the theories of Suess, Wegener, Joly, and Kober, and discussed their application to the origin of the North Atlantic. He (Dr. Tyrrell) suggested that the rifting apart of the continents took place by the subsidence of wedge-shaped masses in a wave of movement from south to north, each subsidence being heralded by eruptions of basalt and dolerite, the earliest occurring in South America and South Africa, in Jurassic times.

Prof. GREGORY and Mr. E. B. BAILEY congratulated Dr. Tyrrell on his lecture, and, on the motion of the chairman, a vote of thanks was accorded to Dr. Tyrrell.

Rev. RAMSAY SIBBALD made reference to the death of Mrs. Gray, and moved that an expression of sympathy be sent to the family. This was agreed to.

The Christie collection of rocks and minerals, which has been arranged for the Society by Miss Neilson, was exhibited at the close of the meeting.

G. W. TYRRELL.

---

207 BATH STREET, GLASGOW, 13TH MARCH, 1924.

The sixth meeting of the sixty-sixth Session—*President*, Dr. G. W. TYRRELL, in the chair.

A paper was read by Mr. J. E. RICHEY, B.Sc., on "The Carboniferous Strata below the Top Hosie Limestone in North Ayrshire." [*See this Volume.*]

Prof. DRON and Mr. MURRAY MACGREGOR congratulated Mr. Richey on his paper, and on the motion of the Chairman a hearty vote of thanks was accorded to Mr. Richey.

J. G. ROBERTS.

---

207 BATH STREET, GLASGOW, 10TH APRIL, 1924.

The seventh meeting of the sixty-sixth Session—Mr. J. G. ROBERTS in the chair.

Dr. TYRRELL read part I. of his presidential address—"Igneous Action and Earth Movement—The Caledonian Revolution." Dr. Tyrrell commented on the parallelism of igneous and tectonic history, and suggested that it might be appropriate to speak of petrographic periods rather than of petrographic provinces, such periods being simply sequences of rock types. Dr. Tyrrell described the phenomena and phases of diastrophism, and analysed the diastrophic cycle of the Lower Palæozoic of Scotland, describing the rock types associated with each phase. The continental phase of the Torridonian showed no igneous activity. This formation probably corresponds to the Sparagmite Sandstone of Scandinavia, which is generally regarded by

Digitized by Google

Scandinavian geologists as belonging to earliest Cambrian times. The Sparagmite formation includes amygdaloidal basalts and quartz-dolerite. In America the continental phase is associated with great floods of basaltic lavas. The submergence (or geosynclinal) and the alternating (or transgression) phases are represented in Scottish Palæozoic igneous activity by outpourings of soda-rich, spilitic lavas, with albite, and by intrusions of serpentine and green-rocks, transformed by earth movements into hornblende-chlorite and talc-schists. In the alternating stage igneous activity is at a minimum. In the final upheaval of the Caledonian Revolution there appears to have been two paroxysms of igneous activity, separated by earth movements; this accounts for the foliation of some of the igneous rocks of this phase, and its absence from others. Granodiorites and andesites are the rock types of the Caledonian Revolution. Andesite lavas occur in the Ochil, Sidlaw, and Cheviot Hills, and are never foliated.

G. W. TYRRELL.

---

207 BATH STREET, GLASGOW, 9TH OCTOBER, 1924.

The first meeting of the sixty-seventh Session—*President*, Dr. G. W. TYRRELL, in the chair.

The President made reference to the retirement of Mr. Sinclair from the office of Librarian, and expressed the Society's appreciation of his long and valuable services.

Obituary notices were then read—on Sir Jethro Teall, F.R.S., by Prof. J. W. GREGORY (communicated by Mr. C. J. Gregory), and on Dr. Robert Kidston, F.R.S., by Dr. PATTON.

A communication was read by Mr. DUNCANSON from Mr. J. A. W. Murdoch, describing the finding of bones of *Megatherium* in the Peruvian Cordillera. [*See this Volume.*]

A paper was then read by Mr. B. H. BARRETT, M.A., B.Sc., entitled "The Permian Breccia of Arran." [*See this Volume.*]

Dr. TYRRELL and Mr. C. J. GREGORY commented on the importance of Mr. Barrett's work, and the difficulty of interpreting the evidence.

Rev. RAMSAY SIBBALD asked Mr. Barrett what was the difference between the Brodick and Machrie pebble-assemblages.

Mr. BARRETT, in reply, thanked the members for their reception of his paper, and stated that at Machrie there were no granites or dolerites, only schists.

G. W. TYRRELL.

---

207 BATH STREET, GLASGOW, 13TH NOVEMBER, 1924.

The second meeting of the sixty-seventh Session—*President*, Dr. G. W. TYRRELL, in the chair.

Messrs. M. A. Peacock, B.Sc., L.R.A.M.; W. J. M'Callien, B.Sc.; B. H. Barrett, M.A., B.Sc.; and J. F. Scott, B.Sc., proposed by Dr.

Digitized by Google

Tyrrell and seconded by Mr. John Weir, were elected ordinary members of the Society.

The following new office-bearers were elected:—

Vice-President (for three years)—Mr. Murray Macgregor, M.A., B.Sc.

Members of Council (for three years)—Herbert Priestly, Robert B. Anderson, Dr. D. N. MacArthur, Alex. M'Lean.

Honorary Librarian—Rev. S. J. Ramsay Sibbald.

Reports of Council, Finance, and Library were read by the Secretary, the Treasurer, and the Librarian. In moving the adoption of these reports, Mr. STEELE suggested that at their election new members should be presented to the President; also that the detailed Librarian's Report should be displayed, to enable members to study the lists of periodicals which had been acquired during the Session. The adoption of these reports was seconded by Mr. Priestly.

Rev. Mr. SIBBALD gave notice of motion to be made at next ordinary meeting that a grant of £10 be made to the Library.

The President referred to the death of Sir Archibald Geikie, and asked Mr. Steele, as the oldest member present, to say a few words. Mr. STEELE gave a few reminiscences of Sir Archibald's association with the Society.

A paper was then read by Mr. W. J. M'CALLIEN, B.Sc., entitled "Notes on the Geology of the Tarbert District." [*See this Volume.*]

Prof. J. W. GREGORY congratulated Mr. M'Callien on his important contribution to the geology of the South-West Highlands. The 1-inch map of the Campbeltown district shows an unconformity between the Loch Tay Limestone and the underlying rocks in that area. With regard to the occurrences of slag which Mr. M'Callien had described, were there no indications of ancient ironworks to account for these? He asked Mr. M'Callien if the age of the faulting in the area could be determined with reference to the age of the north-west—south-east dolerite dykes. Mr. M'Callien believed that the main fjord fault defining lower Loch Fyne was nearer to the Knapdale and Kintyre shore than to the Cowal shore. He (Prof. Gregory) had held that opinion for some time.

Mr. M. MACGREGOR congratulated Mr. M'Callien on his paper, and said that he would like to ask Mr. M'Callien how far he had been able to trace his suggested boundary of the Erins Quartzite and Stonefield schists in a north-east—south-west direction, and whether it was sharply demarcated?

The President said Mr. M'Callien had shown a fine example of geological courage in tackling this very difficult problem. In view of the universal distribution of garnets in the area, would it not be possible to simplify the rock-grouping?

Mr. M'CALLIEN, in reply, thanked the members for their reception of his paper. He had not yet worked out the Campbeltown area in detail, and could not say whether there was an unconformity between

Digitized by Google

the Loch Tay Limestone and underlying rocks in that region, but he thought that the mapping was unreliable. There were no traces of ancient ironworks in the Tarbert district to account for the occurrences of slag. With regard to the age of faults, he had given no consideration to questions of relative age. The boundary between the Erins and Stonefield groups was everywhere transitional. In reply to Dr. Tyrrell, he would say that, instead of simplifying the rock-grouping, he desired still further subdivision.

G. W. TYRRELL.

Digitized by Google

ABSTRACT

OF THE

TREASURER'S ACCOUNTS.

Digitized by Google

ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDING 30TH SEPTEMBER, 1922.

CASH ACCOUNT.

RECEIPTS.

To Balance on hand 30th Sept., 1921:—			
Balance in Bank, ...	£93 2 10		
Cash on Hand, ...	0 16 9		
		£93 19 7	
,, Subscriptions:—			
Ordinary Members—101 at 15/, ...	£75 15 0		
Arrears— 4 at 15/, 1 at 5/, ...	3 5 0		
Lady Members— 7 at 10/, ...	3 10 0		
Life Member—	5 5 0		
Associate Members—11 at 2/6, ...	1 7 6		
		89 2 6	
,, Interest on Funds Invested, including Cowie Prize Fund, ...	£14 7 6		
,, Interest on Funding Loan (Mr. Jas. Neilson), ..	4 0 0		
		18 7 6	
,, Sale of *Transactions*, ...		0 15 1	
		£202 4 8	

EXPENDITURE.

By Library:—			
Magazines, ...	£1 10 0		
New Books, ...	2 10 0		
		£4 0 0	
,, Subscriptions:—			
Palæontographical Society, ...		1 1 0	
Scottish Marine Biological Association, ...		1 1 0	
Natural History Society, Use of Lantern, ...		1 1 0	
,, Cowie Prize Fund:—			
Glasgow University, one-half Interest to Martinmas, 1921, ...	£2 17 6		
Royal Technical College, ...	2 17 6		
		5 15 0	
,, Administration:—			
Printing and Postage of Billets, &c., ..	£20 2 5		
Rent, Lighting, and Attendance, ...	12 2 4		
Hon. Secretary, Treasurer, and Librarians' postages, ...	3 5 10		
		35 10 7	
,, Cash in Bank, ...	£34 14 9		
,, Cash in Deposit Receipt, ...	100 0 0		
,, Cash in hon. Treasurer's hands, ...	19 1 4		
		153 16 1	
		£202 4 8	

Digitized by Google

LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1922.—To Balance to Credit, ...	£235	0	0	Sept. 30, 1921.—By Balance from last Account, ...	£229	15	0
				Sept. 30, 1922.—By New Subscription, ...	5	5	0
	£235	0	0		£235	0	0

COWIE PRIZE FUND.

Sept. 30, 1922.—To Glasgow University, one-half Interest to Martinmas, 1921, ...	£2	17	6	Sept. 30, 1921.—By Balance from last Account, ...	£103	15	0
,, Royal Technical College, one-half Interest to Martinmas, 1921, ...	2	17	6	Sept. 30, 1922.—By One Year's Interest, ...	5	15	0
,, Balance to Credit, ...	103	15	0				
	£109	10	0		£109	10	0

BALANCE SHEET.

To Life Subscription Account, ...	£235	0	0	By Investments:—			
,, Cowie Prize Fund, ...	103	15	0	Exchequer Bonds, 1925, including Cowie Prize Fund, ...			£250 0 0
,, Capital, ...	665	1	1	Funding Loan, ...			100 0 0
				Property Books, ...	£440	0	0
				Bookcase, Furniture, and 1 Microscope, ..	60	0	0
							500 0 0
				,, Balance Cash on Hand, ...	£19	1	4
				,, Cash in Bank, ...	134	14	9
							153 16 1
	£1003	16	1				£1003 16 1

GLASGOW, 29*th November*, 1921.—Examined, compared with relative Vouchers and Securities, and found correct, the Balance in Treasurer's hands being Nineteen Pounds One Shilling and Fourpence stg.

ARCH. MACINTYRE, F.S.A.A.,
ALEX. M'LEAN, } *Auditors.*

Digitized by Google

ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDING 30TH SEPTEMBER, 1923.

CASH ACCOUNTS.

RECEIPTS.

To Balance on hand 30th Sept., 1922:—			
Balance in Bank, ...	£134 14 9		
Cash on hand, ...	19 1 4		
		£153 16 1	
,, Subscriptions:—			
Ordinary Members—98 at 15/, ...	£73 10 0		
Arrears— 6 at 15/, ...	4 10 0		
Lady Members — 6 at 10/, ...	3 0 0		
Life Subscription—	5 5 0		
Associate Members—6 at 2/6, ...	0 15 0		
		87 0 0	
,, Interest on Invested Funds, including Cowie Prize Fund, ...	£14 7 6		
,, Interest on Funding Loan (Mr. James Neilson),	4 3 0		
		18 10 6	
,, Deposit Receipt Interest, ...	... ...	2 15 10	
		£262 2 5	

EXPENDITURE.

By Library:—			
Geological Magazine, ...		£1 10 0	
,, *Transactions*, Vol. XVII., Part 2:—			
Cost including Illustrations, ...	£181 0 0		
Postages and Outlays, ...	3 5 3		
	£184 5 3		
Less:—Grant from Carnegie Trust for Illustrations, ...	£20 0 0		
Glasgow University for Copies of Papers, ...	7 1 0		
Author's extra Copies, ...	11 19 9		
Mitchell Library for 40 Copies, ...	6 15 0		
Sales by hon. Librarian, ...	1 16 7		
	47 12 4	136 12 11	
,, Subscriptions:—			
Palæontographical Society, ...		1 1 0	
Scottish Marine Biological Association.		1 1 0	
Natural History Society, Use of Lantern, ...		1 1 0	
,, Cowie Prize Fund:—			
Glasgow University. Interest to Mart., 1922,	2 17 6		
Royal Technical College, Interest to Mart., 1922,	2 17 6		
		5 15 0	
Administration:—			
Printing and Postage of Billets, ...	£15 9 0		
Rent, Lighting, and Attendance, ...	11 6 0		
Hon. Secretary and Treasurer's expenses, ...	1 10 5		
		28 5 5	
,, Cash on Hand, ...	£20 12 9		
,, Balance in Bank, ...	66 3 4		
		86 16 1	
		£262 2 5	

Digitized by Google

LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1923.—To Balance to Credit,		£240	5	0	
		£240	5	0	
Sept. 30, 1922.—By Balance from last Account,		£235	0	0	
Sept. 30, 1923.— ,, New Subscription,		5	5	0	
		£240	5	0	

COWIE PRIZE FUND.

Sept. 30, 1923.—To Glasgow University, one-half Interest to Martinmas, 1922,		£2	17	6	
,, Royal Technical College, one-half Interest to Martinmas, 1922,		2	17	6	
,, Balance to Credit,		103	15	0	
		£109	10	0	
Sept. 30, 1922.—By Balance from last Account,		£103	15	0	
1923.— ,, One year's Interest,		5	15	0	
		£109	10	0	

BALANCE SHEET.

To Life Subscription Account,						£240	5	0
,, Cowie Prize Fund,						103	15	0
,, Capital,						592	16	1
						£936	16	1
By Investments:—								
Exchequer Bonds, 1925, including Cowie Prize Fund,						£250	0	0
Funding Loan, 1960-1990,						100	0	0
,, Property Books,	£440	0	0					
Furniture, Bookcase, Microscope,	60	0	0					
						500	0	0
,, Balance Cash on Hand,	£20	12	9					
,, Balance Cash in Bank,	66	3	4					
						86	16	1
						£936	16	1

GLASGOW, 24*th October*, 1923.—Examined, compared with relative Vouchers and Securities, and found correct, the Balance in Treasurer's hands being Twenty Pounds Twelve Shillings and Ninepence stg.

ARCHD. MACINTYRE, F.S.A.A.,
ALEX. M'LEAN, } *Auditors.*

Digitized by Google

ABSTRACT OF THE TREASURER'S ACCOUNTS FOR THE YEAR ENDING 30TH SEPTEMBER, 1924.

CASH ACCOUNT.

RECEIPTS.

To Balance on hand 30th Sept., 1923 :—			
Balance in Bank, ...	£66 3 4		
Cash on Hand, ...	20 12 9		
		£86 16 1	
,, Subscriptions :—			
Ordinary Members—87 at 15/, ...	£65 5 0		
Arrears— 10 at 15/, ...	7 10 0		
Lady Members— 7 at 10/, ...	3 10 0		
Life Subscription—	5 5 0		
Associate Members—7 at 2/6, ...	0 17 6		
		82 7 6	
,, Interest on Invested Funds, including Cowie Prize Fund, ...	£14 7 6		
,, Interest on Funding Loan (Mr. James Neilson).	4 0 0		
		18 7 6	
,, Deposit Receipt Interest, ...	... ...	1 1 2	
,, Sales of *Transactions*, &c., ...	.. ...	5 18 3	
		£194 10 6	

EXPENDITURE.

By Library :—			
Geological Magazines, ...	£1 10 0		
New Book Presses, ...	18 0 9		
		£19 10 9	
,, Subscriptions :—			
Palæontographical Society, ...		1 1 0	
Scottish Marine Biological Association, ...		1 1 0	
Natural History Society, Use of Lantern, ...		1 1 0	
,, Cowie Prize Fund :—			
Glasgow University, Interest to Mart., 1923,	£2 17 6		
Royal Technical College, Interest to Mart., 1923, ...	2 17 6		
		5 15 0	
,, Administration :—			
Printing, Postage, Billets, ...	£13 16 1		
Rent, Lighting, and Attendance, ...	11 4 6		
Hon. Secretary and Treasurer's expenses, ...	2 1 6		
		27 2 1	
,, Cash on Hand, ...	£4 12 8		
,, Balance in Bank, ...	134 7 0		
		138 19 8	
		£194 10 6	

Digitized by Google

LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1924.—To Balance in Hand, ...	£245 10 0	Sept. 30, 1923.—By Balance from last Account, ...	£240 5 0
		Sept. 30, 1924.— ,, New Subscription, ...	5 5 0
	£245 10 0		£245 10 0

COWIE PRIZE FUND.

Sept. 30, 1924.—To Glasgow University, one-half Interest to Martinmas, 1923, ...	£2 17 6	Sept. 30, 1924.—By Balance from last Account, ...	£103 15 0
,, Royal Technical College, one-half Interest to Martinmas, 1923, ...	2 17 6	Sept. 30, 1924.— ,, One Year's Interest, ...	5 15 0
,, Balance in Hand, ...	103 15 0		
	£109 10 0		£109 10 0

BALANCE SHEET.

To Life Subscription Account, ...	£245 10 0	By Investments:—			
,, Cowie Prize Fund, ...	103 15 0	Exchequer Bonds, Including Cowie Prize Fund, ...			£250 0 0
,, Capital, ...	639 14 8	Funding Loan, 1960-1990, ...			100 0 0
		,, Property Books, ...	£440 0 0		
		Furniture, Bookcase, Microscope, ...	60 0 0		
					500 0 0
		,, Balance Cash on Hand, ...	£4 12 8		
		,, Balance Cash in Bank, ...	134 7 0		
					138 19 8
	£988 19 8				£988 19 8

GLASGOW, 22*nd October*, 1924.—Examined, compared with relative Vouchers and Securities, and found correct, the Balance in Treasurer's hands being Four Pounds Twelve Shillings and Eightpence stg.

ARCH. MACINTYRE, F.S.A.A.,
ALEX. M'LEAN, } *Auditors.*

Digitized by Google

THE GEOLOGICAL SOCIETY OF GLASGOW.

OFFICE-BEARERS, 1925.

President—

G. W. TYRRELL, A.R.C.Sc., Ph.D.

Vice-Presidents—

DONALD PATTON, M.A., B.Sc., Ph.D. J. G. ROBERTS.
M. MACGREGOR, M.A., B.Sc.

Members of Council—

Miss ETHEL D. CURRIE, B.Sc.
Messrs. E. J. A. STEWART, M.A., B.Sc.
D. M'VEAN, M.A., B.Sc.
J. HOLMES.
Messrs. A. E. SHUTE.
H. PRIESTLEY.
R. B. ANDERSON.
D. N. MACARTHUR, Ph.D.
A. M'LEAN.

Honorary Treasurer—

JAMES BEGG, The Elms, Mount Vernon.

Honorary Librarian—

Rev. RAMSAY SIBBALD, 32 Lilybank Gardens, Glasgow.

Honorary Secretaries—

DAVID B. DUNCANSON, B.Sc., The Training College, Jordanhill, Glasgow.
JOHN WEIR, M.A., Geology Dept., University, Glasgow.

Digitized by Google

Digitized by Google

PUBLICATIONS OF THE SOCIETY.

TRANSACTIONS.—Demy 8vo.

Vol. I. Part 1.—The Geology of the Campsie District. By John Young, LL.D., F.G.S. (3rd edition, revised), 2/
——— Part 2.—The Phenomena of the Glacial Drift of Scotland. By Sir Archibald Geikie, F.R.S. (*Reprint*), (*Out of Print*).
Vol. II. Part 1.—Papers on Local and Theoretical Geology, (*Out of Print*).
——— Part 2.— Do. do. do. ,, ,,
——— Part 3.— Do. do. do. - - - 4/6
Vol. III. Part 1.— Do. [contains "On Geological Time." By Lord Kelvin, F.R.S.], - - - 4/
——— Part 2.— Do. [contains "On Geological Dynamics." By Lord Kelvin, F.R.S.], - - 4/
——— (Supplement)—On the Carboniferous Fossils of the West of Scotland. By John Young, LL.D., F.G.S., and James Armstrong, - - (*Out of Print*).
Vol. IV. Part 1.—Papers on Local and Theoretical Geology, - - 3/
——— Part 2.— Do. do. do. - - 3/
——— Part 3.— Do. do. do. - - 3/
Vol. V. Part 1.— Do. do. do. - - 4/
——— Part 2.— Do. [contains "Geological Climate." By Lord Kelvin, F.R.S.], - (*Out of Print*).
Vol. VI. Part 1.— Do. [contains "The Internal Condition of the Earth." By Lord Kelvin, F.R.S.], 4/
——— Part 2.—Papers on Local and Theoretical Geology, - 4/
Vol. VII. Part 1.— Do. do. do. - 5/
——— Part 2.— Do. do. do. - 5/
Vol. VIII. Part 1.— Do. do. do. - 5/
——— Part 2.— Do. [contains "Polar Ice Caps and their Influence in changing Sea Levels." By Lord Kelvin, F.R.S.], - - - - 5/
Vol. IX. Part 1.—Papers on Local and Theoretical Geology, (*Out of Print*).
——— Part 2.— Do. do. do. ,, ,,
Vol. X. Part 1.— Do. do. do. - - 6/6
——— Part 2.— Do. do. do. - - 7/
Vol. XI. Part 1.— Do. do. do. - - 6/
——— Part 2.— Do. do. do. - - 7/

All parts in hand up to this date may be had by members at a reduced price.

——— (Supplement)—Drift Deposits of Ayrshire. By John Smith, - - - - - - - 3/
Vol. XII. Part 1.—Papers on Local and Theoretical Geology, - - 5/
——— Part 2.— Do. do. do. - - 5/
——— Part 3.— Do. do. do. - - 5/
——— (Supplement)—Natural History of Scottish Zeolites. By J. G. Goodchild, F.G.S., - - - 2/6
Vol. XIII. Part 1.—Papers on Local and Theoretical Geology, - 5/
——— Part 2.— Do. do. do. - - 5/
——— Part 3.— Do. do. do. - - 5/
Vol. XIV. Part 1.— Do. do. do. - - 5/
——— Part 2.— Do. do. do. - - 5/
——— Part 3.— Do. do. do. - - 5/
Vol. XV. Part 1.— Do. do. do. - - 5/
——— Part 2.— Do. do. do. - - 7/6
——— Part 3.— Do. do. do. - - 7/6
Vol. XVI. Part 1.— Do. do. do. - - 7/6
——— Part 2.— Do. do. do. - - 7/6
——— Part 3.— Do. do. do. - - 7/6
Vol. XVII. Part 1.— Do. do. do. - - 7/6
——— Part 2.— Do. do. do. - - 7/6

JUBILEE VOLUME.

HISTORY OF THE GEOLOGICAL SOCIETY OF GLASGOW, - - - 4/6

GEOLOGY OF THE CLYDE DRAINAGE AREA.

Compiled for the Meeting of the British Association, Glasgow, 1901.
Demy 8vo, paper boards, - - - - 1/; interleaved, 1/6

Copies of the above from the Hon. Libn., Rev. RAMSAY SIBBALD, at the Society's Rooms, 207 Bath Street, Glasgow; *or through any Bookseller.*

Digitized by Google

TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

VOL. XVII.—PART III.

1925-1926.

GLASGOW: PUBLISHED BY THE SOCIETY,
AT ITS ROOMS, 207 BATH STREET.
FEBRUARY, 1927.

Titus Wilson & Son,] [*Printers, Kendal.*

PRICE 7s. 6d.

Digitized by Google

Digitized by Google

TRANSACTIONS

OF THE

GEOLOGICAL SOCIETY OF GLASGOW.

No. II.—On an Occurrence of *Sanguinolites abdenensis*, R. Eth., Jun., in North Ayrshire. By W. Manson of H.M. Geological Survey.

The genus *Sanguinolites* was instituted by M'Coy[1] in 1844 to include a group of shells previously classed with *Sanguinolaria*.

In 1877 R. Etheridge, Jun.,[2] described and figured certain lamellibranchs obtained from a bed of shale near the base of the Lower Limestones at Abden, Fife. He referred them to *Sanguinolites*? and on account of differences from the described species of this genus he adopted *abdenensis* as a specific name.

The shore section at Abden (see Fig. 22) was detailed in the Geological Survey Memoir of Central and Western Fife and Kinross-shire, published in 1900.[3] *Sanguinolites abdenensis* was recorded more precisely in this memoir as occurring in fossiliferous shales lying below the first Abden Limestone. Part of the section there given is:—

	ft.	ins.
Limestone (First Abden Limestone)	10	—
Shale with nodules of limestone and marine fossils	1	—
Green and red tuffs	6	—
Dark shale with brachiopods and lamellibranchs	1	6
Soft pale marly shale or fireclay	1	6
Dark shales with a lamellibranch fauna including *Sanguinolites abdenensis*	2	11
Bone bed with numerous fish remains	—	1

Digitized by Google

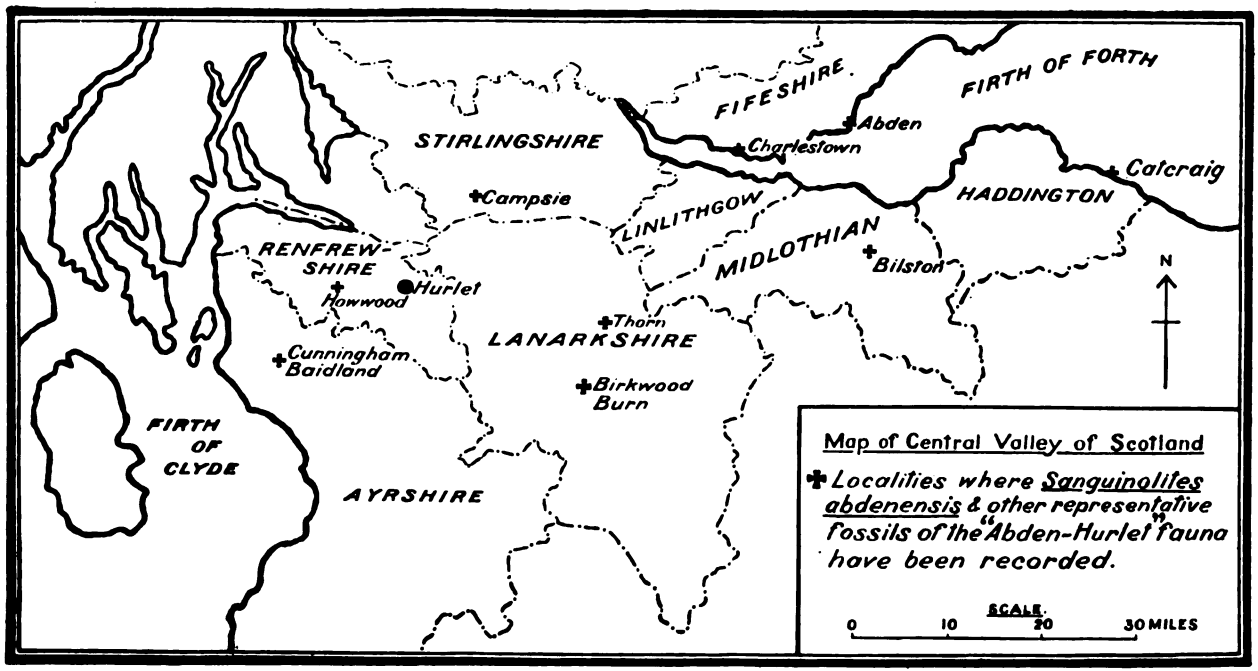


Fig. 22.

Digitized by Google

In 1910 the Geological Survey Memoir on the neighbourhood of Edinburgh was published.[4] In this work reference was made to a brachiopod-bearing shale underlain by a " bone bed " discovered by the late Mr. A. Macconochie. In the Burdiehouse Burn these beds were found underlying a limestone which occurs 130 ft. below the Gilmerton Limestone. In the Bilston Burn they were noted at 80 ft. below the Gilmerton Limestone position and here again the " bone bed " and shale were capped by a limestone. The horizon was correlated with the " bone bed," fossiliferous shale and limestone of Abden.

In 1914, Professor Macnair[5] described the occurrence at Howwood in Renfrewshire, of a bed of shale underlying the Hurlet Limestone, with the following characteristic faunal sequence: (1) in the lower part lamellibranchs-*Sanguinolites abdenensis, Streblopteria ornata, Actinopteria persulcata,* and *Myalina verneuilii*; (2) in the upper part brachiopods—*Schizophoria resupinata,* and *Productus semireticulatus.* Below the lamellibranch shale in the Campsie district he found a " bone-bed " containing fish remains and resting on the Hurlet Coal.

Professor Macnair[5 and 6] carried the correlation of the Hurlet Limestone into Fife and Midlothian, laying stress upon the close resemblance of the Hurlet and Abden successions. Incidentally he completed the comparison between the Abden shore and Bilston Burn by the discovery, in company with Mr. Macconochie, of *Sanguinolites abdenensis,* etc., in the shale separating the " bone-bed " from the overlying brachiopod bed.

At Dr. J. Horne's suggestion an extensive search was made last summer in North Ayrshire for the "Abden—Hurlet" fauna Several exposures of shale separating the Dockra Limestone from the underlying coal were examined. At one outcrop—in the right bank of the Rye Water, 400 yds. E.S.E., of Cunningham Baidland, north-west of Dalry (Fig. 23)—*Sanguinolites abdenensis* was obtained. There, the following section may be seen below the Dockra Limestone in descending order:—

	ft.	ins.
Limestone bands and limy shale (basal beds of Dockra Limestone exposed in adjoining quarries)	3	—
Limy shale with pyritous limy balls and among other fossils, *Sanguinolites, cf. striatogranulatus, Myalina verneuilii, Aviculopecten dissimilis, Lithodomus lithodomoides, Grammatodon cf. reticulatus, Ed-*		

Digitized by Google

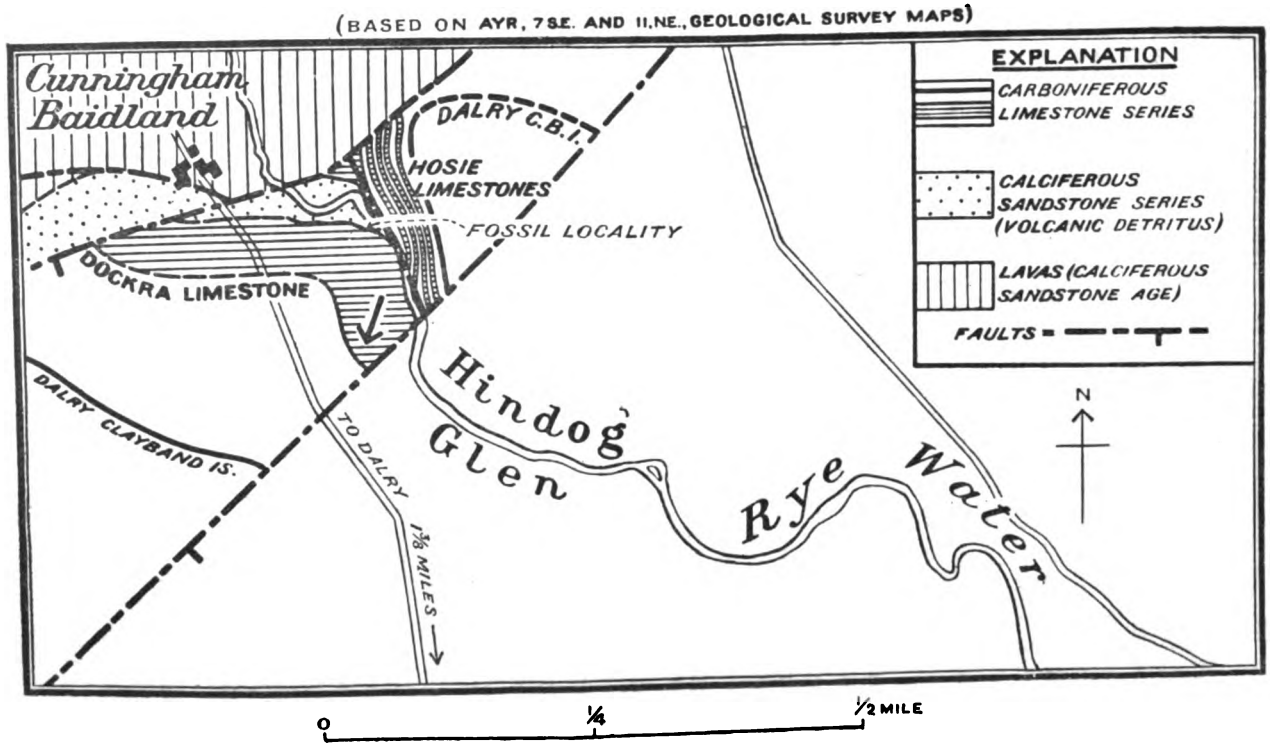


Fig. 23.

Digitized by Google

	ft.	ins.
mondia unioniformis, Sedgwickia scotica, Productus pugilis, Productus of *concinnus* type, *Schizophoria resupinata* and *Camarotoechia pleurodon*	5	—
Marly limy shale with abundant specimens of *Schizophoria resupinata* (corresponding with Professor Macnair's brachiopod bed)	1	2
Marly limy shale with abundant specimens of *Sanguinolites abdenensis* (corresponding with Professor Macnair's lamellibranch bed)	—	4
Blackband Ironstone with fish remains and *Lingula* (corresponding with Abden "Bone-bed") ..	—	2
Coal (corresponding with Hurlet Coal)	—	5
Grey fireclay with rootlets and limy balls.		

Messrs R. G. Carruthers and J. E. Richey[7] have correlated the Dockra Limestone of Ayrshire with the Hurlet Limestone of Renfrewshire, mainly on stratigraphical grounds, and the present record of the occurrence of *Sanguinolites abdenensis* is a valuable support to this correlation.

In conclusion I should like to say that the fossils collected from the locality at Cunningham Baidland have been determined by Dr. G. W. Lee, who has furnished a note upon them for the Summary of Progress of the Geological Survey for 1924.[8] For advice and help with this communication my thanks are due to Dr. G. W. Lee and Messrs. E. B. Bailey and J. E. Richey.

Bibliography.

[1] Synopsis Carb. Foss. Ireland, 1844, p. 47.

[2] R. Etheridge, Jun. "Further Contributions to British Carboniferous Palaeontology." *Geol. Mag.* dec. 2, vol. iv, 1877, p. 246, pl. xii, figs. 9-11.

[3] "Central and Western Fife and Kinross-shire" (*Mem. Geol. Surv.*), 1900, pp. 72-73.

[4] "The Neighbourhood of Edinburgh" (*Mem. Geol. Surv.*), 1910, pp. 161, 162 and 169-171.

[5] P. Macnair. "The Hurlet Sequence in North Ayrshire." *Trans. Geol. Soc., Glasg.*, Vol. xv, 1914, pp. 200-248.

[6] P. Macnair. "The Hurlet Sequence in the East of Scotland and the Abden Fauna as an Index to the Position of the Hurlet Limestone." *Proc. Roy. Soc., Edin.*, Vol. xxxvii, 1917, p. 204.

[7] R. G. Carruthers and J. E. Richey. "The Lower Limestones of Renfrewshire and North Ayrshire: A Comparison and Correlation." *Trans. Geol. Soc., Glas.* Vol. xv, 1914, p. 249.

[8] "Summary of Progress" for 1924. (*Mem. Geol. Surv.*), 1925, p. 124.

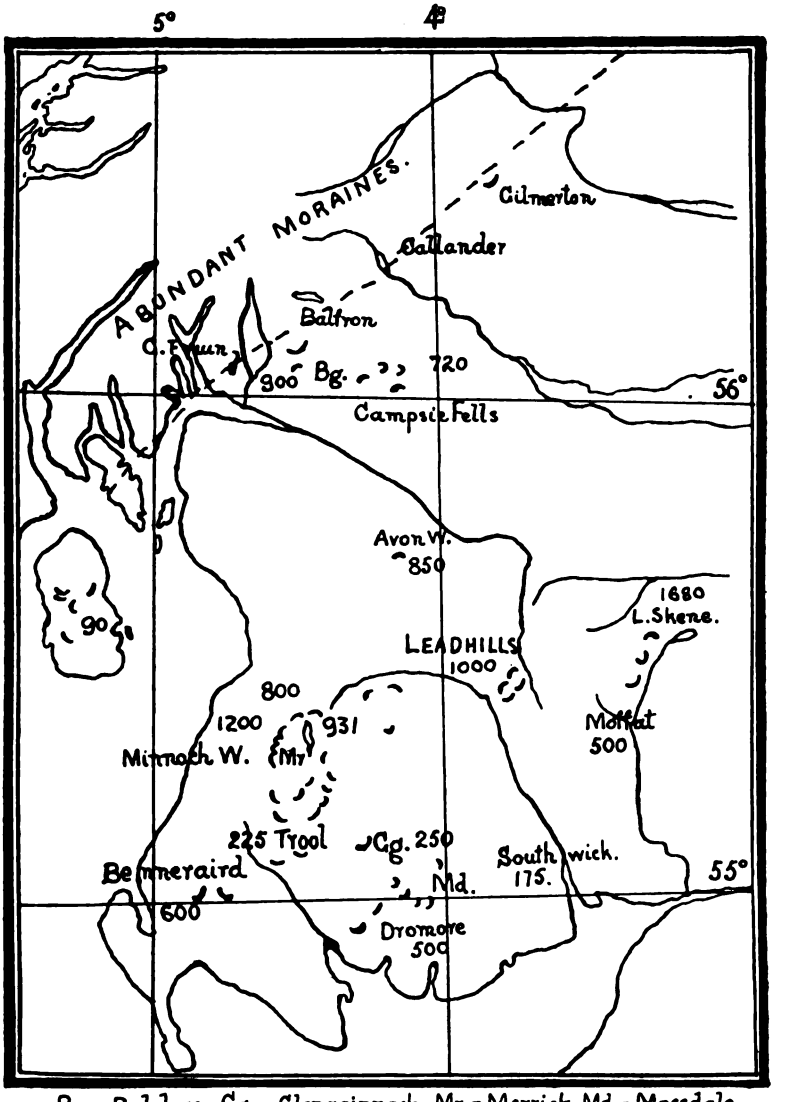
Digitized by Google

No. IV.—The Moraines, Boulder Clay, and Glacial Sequence of South-western Scotland. By J. W. Gregory, D.Sc., F.R.S.

Read 12th March, 1925.

The clearness and abundance of the evidence of glacial action in south-western Scotland is one of the most striking features in its geology. Nevertheless moraines are singularly rare and restricted in distribution, although they are innumerable and well developed north of the Highland Border line. This fact has been often remarked (e.g. Jas. Geikie, 1894, pp. 259-60; W. B. Wright, 1914, p. 82) and it is early impressed on a Glasgow geologist that although drumlins of boulder clay and sheets of fluvioglacial gravel are well displayed around the city, there is no moraine suitable for class excursions nearer than one twenty miles away in Glen Fruin. The contrast between the Highlands and Lowlands as regards moraines is strengthened by the wide distribution of boulder clay in the Midland Valley of Scotland and on the Southern Uplands, and its absence from the Highlands except on the margins and in the lower part of the great straths. This difference in the distribution of boulder clay and moraines appears the more remarkable from the general conception of boulder clay as ground moraine; as if that view were correct it might be expected to occur within the terminal moraines instead of having its chief development outside their range. Further acquaintance with the south-west of Scotland showed that this rarity of moraines is characteristic of nearly the whole of the Midland Valley and of most of the Southern Uplands. Moraines have been often recorded from the southern hills; and their excellent preservation in some localities increases the significance of their absence from many sheltered glens, where, if they had ever existed, they should have been equally well preserved.

Digitized by Google



Bg. = Balglass. Cg. = Glengainnoch. Mr. = Merrick. Md. = Mossdale.

The Moraines of the S.W. of Scotland.

Heights in feet.

Fig. 24.

Digitized by Google

II. The Distribution of Moraines.

The moraines in the south-west of Scotland, south of the Highlands, may be classified into three divisions.

A. The first division includes occasional moraines along the Highland Border, which are due to glaciers from the Highland valleys. Examples of this type include the terminal moraine at Balfron (Gregory, 1915, p. 160) formed around the end of the south-eastern glacier from Ben Lomond; the Glen Fruin moraine (Renwick & Gregory, 1907), one of the southernmost of the numerous moraines formed by the Loch Lomond glacier, and the moraines in the Teith Valley, as at Drumdhu a mile to the east of Callander. Four formations near Crieff are marked as moraines on the Geological Survey Map (sheet 47)—viz. at East Lochlade on the southern side of Ochtertyre Park 1½ miles west of Crieff, at Milton of Cultoquhey 2 miles east of Crieff, and at Conachan on the upper part of the Shaggie Burn north-east of Crieff. These formations would belong to this category, but they are all drumlins or banks of boulder clay. True moraines occur near Crieff south of Loch Turret, but they are on Highland rocks; and a denuded moraine crosses the Shaggie Burn and the Gilmerton-Sma' Glen road from 680 to 740 ft., for three-quarters of a mile, beginning N.W. of the farm of Ibert, a mile and a quarter north of Gilmerton.

The beautiful terminal moraine on the floor of Glen Rosa at Brodick, 90 ft.[1] above sea-level, and the other moraines of northern Arran are due to ice from the Goatfell group which may be regarded as Highland. Some other Arran moraines—such as those across the upper part of the Machrie Burn, the "Serpent Mound" at Monyquil on the northern side of the String Road, about a mile above the main road bridge over the Machrie Water, and the moraine at Drimiginar east of Drumadoon Bay—though situated in the lowlands of southern Arran, were formed by ice from the granite highlands.

B. The second division consists of moraines on the northern slopes of hills in the Midland Valley. It includes numerous small corrie glaciers, which were formed in the last stage of the glaciation

[1] This moraine is the lowest in southern Scotland. Chambers (1855, pp. 104-5) claimed that a glacier from Glen Iorsa in western Arran had reached sea-level after the date of the 25 ft. beach, upon which it had deposited a moraine; but this supposed moraine is a combination of boulder clay and 100 ft. beach material and is earlier than the 25 ft. beach.

Digitized by Google

in hollows where snow was protected from the afternoon sun. Such, for example, is the beautiful little moraine at the height of 900 ft. on the floor of the corrie of Balglass (Gregory, 1913, p. 64), and a small high level moraine in an incipient corrie at the head of the March Burn, just on the northern crest of the range north of Kilsyth, at the height of 1250 ft. (Gregory, 1915, p. 160) Larger moraines of this group occur where the glacier from the highest area of the Campsie Fells reached the floor of the Carron Valley; but the drifts at John de Graham's Castle at the level of about 800 ft. above sea-level I regard as a fluvioglacial delta (Gregory, 1915, p. 175). Some small moraines recorded in the higher valleys of the Ochils (A. Geikie, 1901, p. 388) may be referred to this division.

C. The third and most important division includes a series of eight moraine groups around the higher peaks of the Southern Uplands. (1) The highest summit in Scotland south of the Highland Border Fault is Merrick (2764 ft.), near Loch Doon. Well preserved moraines occur on all sides of the Merrick and the associated mountains around Loch Doon. They are seen, for example, on the road from Dalmellington to Carsphairn (alt. 550-650 ft.) and thence they are seen at intervals on the eastern bank of the Waters of Deugh and Ken to Dalry. For example a conspicuous mound of morainic drift occurs just where the road is joined by the Muck Water, 3 miles south-east of Dalmellington, at the height of 931 ft. Then southward over the moorland there is abundance of morainic drift with moraines at 700 ft. on the shore of Loch Doon and near Carsphairn. Many clear sections in road cuttings and typical morainic ridges are seen on the Carsphairn-Dalry road on the eastern side of the Water of Deugh, between Carsphairn and Burnfoot, at the height of 550-600 ft. The morainic drift continues along the high road past Earlston to Kenbank, with some well-developed morainic hummocks on the floor of the valley, at about 400 ft., near the junction of the Water of Ken and the Water of Deugh.

On the northern side of the Loch Doon mountains boulder clay is seen but no moraine between Dalmellington and Straiton; on the road south from Straiton to Newton Stewart morainic drift occurs near the bridge over the Water of Stinchar at about 1200 ft., and around the divide are a little over 1400 ft. Descending the valley of Pilnyark Burn morainic drifts occur upon its floor; further south around the confluence of the Minnoch Water and Shalloch Burn is a wide tract of moraines at about 800 ft. They

Digitized by Google

extend along the floor of the valley for four miles southward to Palgowan (600 ft.). Moraines, which are also marked on the Geological Survey map, sheet 8, occur a mile further south, between 500 and 600 ft., but they are absent from the floor of the valley. The southernmost of these moraines is near the junction of the Water of Minnoch and Water of Trool at the level of 225 ft. It is recorded on the MS. 6 inch map of the Geological Survey, to which I was kindly referred by Dr. Horne and which was shown me by Mr. Murray Macgregor. Morainic drift at a slightly lower level occurs just S.W. of the Minnoch Water series, beside the bridge over the Cree on the road from Straiton to Newton Stewart. Further south the Cree flows over a level plain of alluvium; from the road I saw nothing definitely morainic. Near the north of Loch Trool moraines are numerous and well preserved; those around the lochs to the S.E. of Merrick have been described by William Jolly, Trans. Geol. Soc. Edinb., Vol. 1, 1868, pp. 175-7, and as has been pointed out to me by Mr. W. R. Gourlay, C.S.I., they are mentioned in Dick's "Highways and Byeways in Galloway." Jolly clearly recognised that the moraines belong to a later period than the previous complete glaciation of the whole district.

South of the Loch Doon granite some denuded moraines at almost 600 ft., were pointed out to me by Mr. Gourlay, on the summit of the old Edinburgh road from Newton Stewart to New Galloway to the W.S.W. of Clattering Shaws. They lie at the north-western foot of Cairnsmore of Fleet. At lower levels along this road both towards Newton Stewart and New Galloway I saw only boulder clay.

To the north of Merrick moraines are recorded on the Geological Survey map on the Water of Girvan at the level of 800 ft. north of Lake Bradan.

The Loch Doon-Merrick granite mass is therefore surrounded by a band of moraines which generally descend to between 800 and 600 ft., and reach their lowest level, 225 ft., near the confluence of the Trool and Minnoch Waters; still lower morainic drift occurs on the Cree at about 150 ft. at Clauch-aneasy.

(2). Moraines are also numerous and reach low levels on the flanks of Cairnsmore of Fleet (alt. 2331 ft.). They are seen from the railway between Gatehouse of Fleet Station (Dromore) at 500 ft. and New Galloway Station.[2] Dr. Horne has referred me

[2] An anonymous article in the Galloway News, 7th Dec., 1923, describes

Digitized by Google

to the Geological Survey manuscript map, which has been kindly shown me by Mr. Macgregor, of the area north of Loch Skerrow; it records moraines along the Glengainoch Burn down to 250 ft. near its junction with the Dee. These Glengainoch moraines may be seen from a hill beside the railway near the 11½ mile post. The drifts in the railway cuttings thence eastward to Stroan Viaduct over the River Dee are in boulder clay; but east of that viaduct is morainic drift at the still lower levels of 234 to 215 ft. This morainic drift also occurs at Mossdale, W. and S.W. of New Galloway Station. The section in the railway by the 9¾ mile post east of the Stroan Viaduct at the level of 234 ft., appeared from the railway train distinctly morainic, while the hummocks between the railway and the river presented the form of moraines. For guidance to them subsequently, I am indebted to Mr. G. F. Scott Elliot.

The section east of the Stroan Viaduct consists of morainic drift, resting on a ridge of whin, (*i.e.* graywacke) to the east. The drift has a sandy base; it includes boulders of granite up to 6 by 5 ft. in diameter, of whin and of a contact schist. One of the included stones was ice-scratched. The material is not boulder clay, as the base is not clay, and ice scratched stones are rare. It is not fluvioglacial as there is no well defined bedding and few water-worn stones. The section is briefly described and the drift identified as moraine in the Mem. Geol. Surv. Scotl., sh. 5, 1896, p. 36, and the material is clearly distinguished from boulder clay and from that of kames. Similar morainic drift occurs at about 215 ft. near the river Dee, S.W. of New Galloway Station, in some moraine-like ridges and mounds on the floor of the valley. Their form is due to the drift resting either on ridges of boulder clay or rock. These Mossdale morainic drifts are either remnants of a sheet of ground moraine or of terminal moraines left by the receding glacier down the valley of the Black Water of Dee,

(3) Criffell itself apparently has no definite moraines as remarked in Geol. Surv. Scotl., Mem. Sh. 5, 1896, p. 36. Boulder clay occurs at the height of 1200 ft. (*Ibid.*, p. 33), and though I have not been to the summit of the mountain I have not seen

White Hill at Kirkdale on the shore of Wigtown Bay as a moraine only 150 ft. above sea-level. Dr. Horne, however, tells me that it is marked on the Geological Survey map as boulder clay. The same article mentions moraines at Culcronchie Viaduct, 311 ft., but the drifts there appear to be boulder clay.

Digitized by Google

anything on it that looked morainic. The western hills of the Criffell group nourished glaciers which gave rise to moraines, one of which is the lowest I know on the mainland of southern Scotland. It is situated a few yards N.W. of the Southwick railway station at the level of 175 ft. It is a low ridge, of which the structure is well exposed. The material is slightly bedded, with a dip to the east. It includes boulders 4 ft. by 3 ft. in diameter; and at the eastern side many granite slabs are jammed together in a pile. Their aspect at first was that of granite blocks *in situ*; but morainic drift occurs below and between some of them; they may have been carried only a few yards.

(4) Small moraines occur on both main slopes of the Lowther Hills (2377 ft.); at levels of over 1000 ft., but though glacieluvial kames occur beside the railway near Thankerton, there are apparently no moraines on the Beattock Pass (alt., 1029 ft.).

(5). In the hills around Loch Skene, which rise to the heights of 2695 and 2262 ft. moraines occur on the Meggat Water down to the level of 1000 ft., and on the Moffat Water down to 500 ft. A member of this group is the well-known moraine-dam of Loch Skene. (1680 ft.).

(6). In the south-western part of the Southern Uplands, numerous moraines are recorded in the Geological Survey Memoir (Sheet 15, 1871, p. 40) in the valleys south of the Kype to the west of the Upper Nith.; they occur in the headstreams of the Water of Ken down to 950 ft.; near the head of the Shinnel Burn at about 1000 ft., and there are others at higher levels.

(7). The ridge near the head of the Avon Valley, which is marked on the six inch Ordnance map (Ayrshire, XXV, N.W., 1912) as the "kames of Avon," (alt., 850-900 ft.), has been identified as a moraine by Mr. John Smith (1898, p. 67). Its form and composition show that it is due to a glacier that flowed down the northern slopes of the Distinct horn (1258 ft.). Some of its constituents, such as the oil shale pebbles, however, have doubtless reached it from the north, but they were probably obtained from the boulder clay.[3]

(8). The south-eastern slopes of Benerairdl (alt., 1433 ft.), the highest summit west of the Cree-Girvan Valley, has moraines of which the lowest members are seen beside the railway south of

[3] Mr. George Ross at the meeting announced the occurrence of a corresponding moraine north of Priesthill.

Digitized by Google

Barrhill and near Glenwhilly at levels of 600-700 ft. The moraines at 600 ft. further east at Loch Moan, belong to the series in the valleys of the Cree and Minnock Water.

Restricted Distribution of the Moraines.

In addition to these eight groups doubtless other moraines occur in the south-western Uplands. During my earlier years in Scotland it was a constant surprise not to find moraines more often among these hills. I have often examined their northern faces, confident that corrie moraines must be there. They may occur in unvisited depressions; but I have searched many apparently likely localities in vain. Thus the northern fronts of Carlock Hill and of its neighbour Beneraird (1433 ft.) near Ballantrae have hummocks of boulder clay but no morainic drift, though it is conspicuous on the south-eastern slopes of Beneraird down to the level of 600 ft. near Glenwhilly.[4]

Boulder clay rises nearly to the summit of Beneraird and the record of " gravel pits " on the six-inch maps to the W. and S.W. of the cairn suggested the possible occurrence of a morainic drift; but these gravel pits are in a rubble of the flags disintegrated by frost.

Enquiries of geologists who know south-western Scotland so well as Dr. Horne,[5] Dr. Tyrrell, and Dr. F. Mort, were answered by reference to moraines included in the foregoing classification.

[4] Mr. J. Smith has suggested (Glac. Drift Ayrsh., *Trans. Geol. Soc., Glasg.*, xi, suppl. 1898, p. 18), that some banks of drift on the floor of the Stinchar Valley above Colmonell are moraines at the level of 120 ft. above the sea. If so, they would be the lowest moraines on the mainland in the S. of Scotland. The banks in question are at and opposite Clauchanton Scaur, ½ mile E.N.E. of Colmonell. I regard them as the remains of a sheet of rubble drift washed out of the boulder clay and collected during the post-glacial re-excavation of the valley. Mr. Smith suggested as an alternative that the material is interglacial; but there seems no evidence that it was ever covered by boulder clay or other glacial deposit.

[5] In answer to an enquiry to Dr. Horne as to the lowest moraines in the S.W. of Scotland, he kindly, after consulting the six inch maps in the Geol. Surv. Office, sent me the following list:—" Moraines are recorded at a level of about 250 ft., a little north of Loch Skerrow, about 3 miles W. by S. of New Galloway Station, Sh. 5, one inch; also at 225 ft. in the valleys of the Trool and Minnoch Waters W. of the Merrick range, Sh. 8, one inch. Moraines are well developed on both sides of the Minnoch Water as far N. as Shalloch on Minnoch (between 300 ft. and 800 ft. levels). They spread westwards by Loch Moan to the head waters of the River Cree, about seven miles W. of the Merrick."

Digitized by Google

Any additional moraines that may be found will therefore probably not invalidate the following conclusions as to their distribution.

1. That moraines are absent from large areas of boulder clay in the Midland Valley and on the Southern Uplands.

2. That on the Southern Uplands extensive moraines occur only around the higher mountain groups where there are considerable areas more than 1500 ft. above sea-level.

3. That there are small corrie moraines on the northern fronts of the hills in the Midland Valley and in the Southern Uplands, where snow accumulated in recesses sheltered from the south-western sun.

4. None of these moraines reach the coast; the lowest, 175 ft. at Southwick, at 225 ft. and 250 ft. occur where the Urr, Cree and Dee Valleys have lowland at the foot of granite hills of Criffell, the Merrick (2764 ft.) and Cairnsmore of Fleet (2331 ft.). In the other groups mentioned the lowest moraines are respectively at over 1000 ft.; 500 ft. in the Moffat Water and elsewhere 1000 ft.; 850 ft.; and 600 ft.

5. The moraines are later than the boulder clay.

III. The Boulder Clay.

Outside the moraines the glacial deposits consist of boulder clay and of sands and gravels of fluvioglacial, glaciolacustrine and glacieluvial origin. Boulder clay is the typical glacial product of the Midland Valley and the Southern Uplands. The name is however applied in Scotland to two very different materials, the till which is characteristic of the Lowlands and the coastal plains of Scotland, and the sandy drifts of the Highlands. The Lowland boulder clay or "till" is a stiff tough clay containing boulders and pebbles, most of which, sometimes almost all, are ice scratched and faceted. The other material includes most of that which, in the Scottish Highlands, is marked as boulder clay on the maps of the Geological Survey; it is, as for example in the area of Sheet 45, a coarse irregular sandy drift, in which the pebbles and boulders are usually angular and unscratched.[6] This sandy drift was probably

[6] A recent search in a long section of this Highland "boulder clay" in the Tilt Valley near Marble Lodge by a party of Univerity students did not yield a single ice-scratched stone. In other cases occasional specimens are ice-scratched. Boulder clay which is clay and contains many ice-sctatched stones occurs in some places in the Highlands, as in Jamieson's section at Tynateid, Killicrankie. This material is glaciolacustrine and is very

Digitized by Google

formed as ground moraine, and it passes into numerous moraines.

Some of the interpretations of the Lowland boulder clay depend upon its identification with the essentially different boulder-bearing sandy drifts of the Highlands

The presence in the lowland type of boulder clay of marine shells and foraminifera is another striking difference from morainic drifts. The shells are as a rule sparse and broken, but their distribution is widespread. Their presence has been observed by most students of the Scottish boulder clay, including T. Mellard Reade (1897). The distribution of the shells has been carefully recorded by Mr. John Smith, who has found them ranging from below sea-level to the height of 1,061 ft. I have found them up to about the same level. The shells are all marine; they indicate cold conditions; and they are sometimes ice-scratched. Some of them appear to have been broken by the shrinkage of the clay during its settlement. They are frequently (cf. *e.g.*, Reade, 1897, p. 118; J. Smith, 1898, pp. 51, 57; V.A. Eyles, in Sum. Progr. Geol. Surv., 1921, p. 78) accompanied by the epidermis. These facts are not favourable to the hypothesis that the shells have been carried inland by glaciers. The shells in the higher Ayrshire drifts occur where the movements of the glacier were seaward, and there seems no evidence of any advance of ice from the sea as high as the upper shell-bearing clays.

No doubt in some cases shell fragments in glacial drifts are derived from other beds; but the foraminifera and fragile shells in the Ayrshire "till" appear to offer as trustworthy evidence regarding its formation as that given by fossils in regard to other beds. For the bulk of the boulder clay of the S.W. of Scotland I am constrained to agree with those who, like James Neilson, Robert Craig, T. Mellard Reade, Mr. John Smith, and Mr. A. Stevens, have accepted the shells as indigenous and as evidence of its marine formation.

Some layers interbedded in the boulder clay contain the teeth and bones of mammals and land plants; but these terrestrial beds are not boulder clay. They indicate interglacial episodes and an

different from the sandy drift. In Canada large tracts of boulder-bearing sand are also called boulder clay. The identification by geologists of sand as clay sometimes causes perplexity; and it would tend to harmonise glacial geology and general usage if deposits in which the base consists mainly of sand were named glacial drifts or boulder sands, instead of boulder clay. Jas.[1] Geikie (1914, pp. 166-7) refers to the restricted range of till in the Highlands.

Digitized by Google

alternation of aqueous and land conditions, which may be regarded as the usual isostatic oscillation consequent on variation in the extent of the ice. An interglacial period, owing to the reduction in the ice load, is naturally a time of uplift. It now appears evident that the British Isles shared the successive increase and decrease in the ice well established for the Alps. Accordingly variations in the land level would be expected. A considerable subsidence would have been caused by the maximum glaciation and short oscillations would have led to the land episodes marked by the two or three bone-bearing horizons in the Scottish glacial drifts.

The introduction of the marine shells by uplift by glaciers would require the overflow of Ayrshire by ice from the Firth of Clyde. Glaciers are rivers of ice and like rivers flow from higher to lower levels. A glacier flowing against a slope will rise up it; but only if the ice is flowing from a higher level than the land it overlaps. Ice from the Scottish Highlands doubtless once filled the Midland Valley and flowed across it and overrode part of the Southern Uplands. That movement was the result of the greater height of the Highlands. West of Ayrshire the only higher mountains are in Arran, the ice of which did not reach the mainland. Cowal, which rises to 2557 ft., is higher than the Ayrshire coast plain; but it has no peaks as high as those of the Southern Uplands, and there is no reason why ice from that peninsula should have forced aside the ice from the greater ice-collecting grounds of the Southern Uplands.

In the absence of any adequate area of higher land to the west and N.W. from which ice can have flowed on to Ayrshire, and in the absence of any Arran[7] and Cowal erratics—the Highland erratics there having come from further east—there seems no evidence of any land ice having invaded Ayrshire from the west. The suggestion that ice from the Firth of Clyde flowed inland to the height of 1000 ft. requires as clear evidence as would the claim that the Ayr and Irvine rivers had their sources in the estuary and flowed thence on to the high moorland peat bogs.

The occurrence of occasional boulders standing on end, as if they had fallen through water, is also an indication of the subaqueous

[7] The occurrence of Arran granite in Ayrshire has been recorded; but none of it has been seen there by Dr. Horne, Mr. John Smith, Dr. Mort, Dr. Tyrrell, nor myself. Cf. J. Smith, *Trans. Geol. Soc., Glasg.*, IX, 151.

Digitized by Google

origin of the boulder clay. The boulder clay has the characteristics of an aqueous deposit that was formed in basins where there was no free drainage, so that the clay was deposited with the sand and boulders. The formation of terrestrial boulder clay under, such conditions I have described as in progress in Spitsbergen where a lateral glacier had converted the upper part of the Fulmar valley into an almost closed basin; (Gregory, 1915, p. 227). Such basins could not, however, have occurred to any large extent on the Ayrshire hills.

That the boulder clay has the characteristics of a water-deposit was pointed out by Carvill Lewis (1894, pp. 47, 49, 58, 388) who attributed it to deposition in glacial lakes. Such a lake in the S.W. of Scotland would have required a succession of ice barriers to the west up to the level of over 1300 ft. Mr. John Smith rejects the possibility of high-level glacial lakes in Ayrshire due to a western ice barrier, with the remark that to state the case for them is to answer it.

The interpretation of boulder clay as ground moraine is not supported by the glacial geology of Antarctica. Large areas have been uncovered from beneath the ice sheet, and if boulder clay be ground moraine, it should be widely distributed there; but its absence is reported by the geologists who have studied the area (*e.g.* R. E. Priestley, Brit. Terra Nova Ant. Exped. 1910-13, Physiography, 1923, p. 79). On the other hand the floor of the Ross Sea is described (*Ibid.*, p. 81) as covered by a deposit which on drying will be boulder clay.

The boulder clay, though aqueous, does not resemble fresh-water deposits, which are generally well assorted, as they are free from the immediate precipitation of fine clay which happens in salt water. The boulder clay of south-western Scotland appears to have been desposited in a quiet ice-covered sea (*cf.* T. M. Reade, 1897, pp. 118, 127-9), in which, owing to the muddiness of the water, the darkness due to the ice cover, and the poverty of vegetable life, animals were scarce.

IV. Conclusions from the Absence of Moraines.

The absence of moraines from any locality is not necessarily proof that it had no glacier at the time. There may be cases in which land ice disappeared from an area and left not a moraine behind. The ice may have swept all loose material into the adjacent seas, and the last would have been clean and have had

Digitized by Google

no material for moraines. This explanation is not, however, applicable to the S.W. of Scotland during the deposition of the boulder clay. The loose material had not all been swept away. The country was covered by a thick mantle of glacial drift and there was abundant material available for moraines.

It may also be suggested that the boulder clay was deposited by a glaciation of which the moraines have been destroyed, and that the existing moraines belonged to a later local glaciation. Many of the lower glens are, however, as well adapted for the preservation of moraines as those that still contain them at higher levels. The existing moraines in southern Scotland were due to glaciers which flowed over the boulder clay, probably on the re-emergence of the land. Any moraines earlier than the boulder clay were naturally destroyed by the processes which made that formation. The distribution of the moraines agrees essentially with the extension of the Mousterian—Aurignacian glaciation in Britain, as shown in the small scale map by Osborn and Reed (1922, p. 442).

The view that moraines once existed beyond their present range and that they were swept away by denudation is inconsistent with the hypothesis that the form of the boulder clay drumlins is due to direct glacial deposition and not to subsequent denudation. The assumption that denudation annihilates moraines, and has no effect on drumlins does not seem plausible.

The different distribution of boulder clay and moraines indicates their formation under different conditions. Moraines are the characteristic product of glaciers; whereas the boulder clay of the S.W. of Scotland—which is a very different material from that called boulder clay in some other places—was deposited by an agent which did not make moraines.

V. The Rock Surface Moulded by Land Ice.

Nevertheless although the boulder clay of south-western Scotland appears to be a marine deposit, the rock surface on which it rests shows abundant evidence of the action of land ice. The rock surfaces are frequently moutonnée, the hills have smooth ice-worn fronts and are rough and irregular on the lee side; and regular parallel striation and fluting due to ice abrasion cross the country in directions determined by the slope. The ice moved in general outward from the mountains, scouring out hollows with the thoroughness indicative of such a plastic agency as glacier ice.

Digitized by Google

The boulder clay was laid down on a rock surface which had been swept and carved by land ice.

The subdued relief of southern Scotland was probably largely due to pre-glacial denudation. Southern Scotland, during part of the Pliocene was from 1000-1200 ft. lower than its present level. The country was then worn down to a peneplane with gentle relief and down-like contours. The harder rocks doubtless stood up as frost-riven crags which would have been reduced to rounded hummocks when the country was covered by ice. The low relief of the country as a whole was doubtless due to the long-continued sub-aerial denudation of pre-glacial times.

VI. The Glacial Submergence.

The sequence of events suggested by the evidence may be summarized as follows:—The land ice accumulated most largely on the Highlands and flowed south into the Midland Valley, where it would have been much thicker as the average level is 1000 ft. lower than the Highland plateau. The isostatic subsidence that usually accompanies heavy glaciation then led to a wide subsidence, which would have been greater in the Midland Valley and Firth of Clyde than on the mountain as the ice load was heavier. Evidence for the submergence of parts of the Scottish coasts in glacial times is overwhelming. The shell bed at Clava was interpreted by all but two of the members of the British Association Committee which reported on it in 1893, as demonstrating that the country near Inverness had been submerged for over 500 ft. (Rep. Brit. Assoc., 1893, p. 512).

Evidence of floating ice is afforded in western Ayrshire at the height of 376 ft. above sea-level near Lugton Station. An exceptionally well exposed glaciated surface 33 yards long was exposed there by quarrying during 1906. Some large scratched surfaces are preserved at the University in the Hunterian Museum and in the collection of the Geological Department. The evidence is described in a paper (Gregory, 1907, pp. 10-18, pl. 1 and 2). I have, however, to alter the conclusion expressed in that paper that the striation was the work of a glacier. Several features in the quarry, such as the curved concentric striae and the quick disappearance of the high polish on the limestone after exposure, suggested that the scratches were due to floating ice, for the striation was effected under water or wet mud, and the surface was first exposed to the air when it was bared by quarrying.

Digitized by Google

On the other hand a groove on a vertical face appeared easier to explain as glacier cut, though it may have been due to an ice floe that had been forced against the face of the limestone reef; but as I then shared the general view that British glaciation was almost entirely the work of land ice, I was led to attribute the Lugton surface to a glacier.

This conclusion introduced difficulties which on further study of the area appear insuperable. The movement of the ice at that spot was from S.W. to N.E.; that direction was regarded as unquestionable by Mr. Reid, the owner of the quarry, and Mr. Fingland, the University Photographer. Some boulders, which had been plucked from the surface of the limestone, had been carried a few yards N.E. and piled against a step in the limestone; some of these boulders were left on end and the clay between them is overfolded by pressure from the S.W. The worn edges of joint cracks in the limestone also showed that the movement was to the N.E. It was this conclusion that led me to describe the quarry in detail, as the reverse movement down the valley appeared the natural direction. The assumed glacier must either have come from Arran, or from the Renfrewshire hills and have been forced back to the N.E. by ice from Arran in the lower part of the Lugton valley. Obstruction by Arran ice then seemed probable, for boulders of Goatfell granite had been recorded in Ayrshire; but as previously remarked, it does not seem to occur there, and the old record may be dismissed as based upon a misidentification of granite from Loch Doon. The advance of land ice up the Lugton Valley from the S.W. appears inexplicable and the striation includes curved concentric scratches similar to those made by floating ice. The long regular striae are traversed by curved crescentric striae as well as by straight cross striae, which are sometimes so crowded as to give the rock a light colour owing to the hatching. This cross striation is of the same date as the major striae, being sometimes earlier and sometimes later. The varied direction of the striae on one slab, as on that in the Hunterian Museum, agrees with what would be expected from floes rising or falling with the tide, combined with horizontal drift along the coast under the influence of wind or current. The curved concentric striae exactly resemble those due to blocks of stranded ice,[8] when swung around by wind or tide.

[8] Some broad short abruptly ending striae suggest the sudden impact and removal of a stone carried in floating ice.

Digitized by Google

In a note in the Summary of Progress of the Geological Survey for 1920 (p. 30) it was pointed out that in an exposure close to Lugton Quarry, the ice movement is in the opposite direction.[9]

On reconsideration therefore of the glaciation of the Lugton Quarry I regard the nature and varied directions of the striae, the high polish on the limestone until exposed to the air, the marine shells in the boulder clay of the district, the predominant ice movement at the quarry from the S.W., and the absence of any possible barrier to the west that would explain the flow of a glacier towards the N.E., as together indicating that the glaciation at Lugton was due to drifting coast ice.

VII. Transport of West Scottish Boulders.

Floating ice along the Ayrshire coast appears the natural explanation of the distribution of the erratics derived thence. Dr. Wills has recorded analcite-basalt boulders from Ayrshire in the Severn Valley at the height of 200-300 ft. near Ironbridge, at about 300 ft. at Morville (Wills, 1924, p. 290), and at about 200 ft. at Bridgenorth (*op. cit.*, pp. 295 and 296). Boulders from Skye have been found in Anglesey by Dr. E. Greenly (1919, pp. 713, 734, 737). Their transport has been attributed to glaciers; but the glaciers would have flowed athwart the main ice movement in western Scotland, as shown by the maps of Sir A. Geikie (1901, pl. 4), his later map in Bartholomew's Atlas of Scotland (1912, p. 14) and that by Wright (1914, p. 49). The transport of these boulders by drifting ice presents no difficulties, for floes from the western Highlands that drifted southward would have been carried by the prevalent westerly wind through the North Channel into the Irish Sea. This process appears also the easiest explanation of the transport of analcite-basalt from Ayrshire to the Severn Valley, and of the scattering of paisanite from Ailsa Craig along both shores of the Irish Sea. Ailsa Craig would have been an ideal centre for the dispersal of material by floating ice through the North Channel; but it is not a promising centre of dispersion by glaciers.

[9] In the Summary of Progress for 1921 (p. 78) it is however pointed out that the transport of boulders near Mauchline affords clear evidence of a movement of ice from the west even at higher levels and further inland than at Lugton. The eastward and south-eastward transport of boulders has been reported by D. M. Horne, Fin. Rep. Boulder Com., Proc. R. Soc., Edinb., xii, 1884, pp. 785-6.

Digitized by Google

VIII. The Correlation of the Scottish and British Glacial Drifts.

The correlation of the moraines of south-western Scotland with the glacial sequence in England and the Continent is difficult, as Scotland was not inhabited by Palaeolithic man and none of his implements are available. The mammal bones and teeth found in the Scottish drifts offer the best evidence; but the successive mammal faunas overlap and species survived in some places later than in others. It is unnecessary to enter into the correspondence of the English and Continental glacial drifts, for the general succession of the English glacial deposits is fairly established. It begins, after the warm period of the Cromer Forest Bed and its early Chellean implements, with the lower glacial drifts, such as the Cromer till, which are followed by deposits with Chellean and Lower Acheulian implements. In these lower glacial deposits the characteristic mammal is *Elephas antiquus*. The mammoth, *E. primigenius*, occurs in the Forest Bed, but it is chiefly found in higher levels, and is characteristic of the Upper Acheulian, before the advent of the reindeer. After the Acheulian the climate again became more severe and the upper Chalky Boulder Clay was contemporary with Mousterian man and with both mammoth and reindeer. In the next stage, that of Aurignacian man, the mammoth still survived in South Wales; the climate was warmer then and in the succeeding Solutrian, after which increasing cold led up to the Arctic conditions of the Magdalenian. In that stage the mammoth still lived on the Continent, but was apparently extinct in Britain, and the reindeer was so abundant that the Magdalenian and Solutrian have been called " the reindeer age." Then, after a long interval, followed the warmer Azilian stage, during which Scotland was reached by Azilian man, who is regarded as upper Paleolithic, or early Neolithic, or as a transitional Mesolithic type. The marine shells of the Azilian still live in the adjacent sea, and the climate was probably somewhat warmer than at present.

This succession indictes three cold periods in England, those of the lower boulder clay which is early Chellean; the Chalky Boulder Clay which is partly Mousterian; and the Aurignacian-Magdalenian. In the correlation of these divisions with the four continental glaciations, the two first, the Gunz and Mindel, may be older than any British glacial drift. The Chellean, Acheulian and Lower Mousterian are probably correctly correlated by Penck

Digitized by Google

and Bruckner, as the Riss; and on that determination the Upper Mousterian, Aurignacian and Magdalenian would correspond to the Wurm—the correlation adopted amongst others by Osborn and Reed (1922, pop. p. 470). The Wurm is, however, correlated by some authors, such as Obermaier, with only the Upper Mousterian and early Aurignacian.

The Scottish Sequence.

Scotland has yielded no Chellean or Acheulian implements, and no *Elephas antiquus*; and it has no human relics corresponding to those in the lower implement-bearing gravels of southern England. The first Scottish glacial bed of which the age is indicated by fossils is that at Kilmaurs near Kilmarnock; it yielded mammoth tusks and various seeds from the earth in the hollow of a tusk which is now in the Hunterian Museum. The exact position from which these tusks came is known from the original reports of Couper and Scouler (reported by Smith of Jordanhill, 1838), the re-opening of the section by James Bryce (1865), and the work of Young and Craig (1869). The mammoth was associated with the reindeer and the tusk came from a land or fresh water deposit underlying a clay with Arctic marine shells. This shelly bed was overlain by 15 ft. of boulder clay, on which lay 20 ft. of upper drifts containing no striated stones. As the many mammoth remains at Kilmaurs were associated with plants, Bryce compared the horizon to the Forest Bed of Cromer; but it was probably later as the only elephant found was the mammoth. The tusk that yielded the seeds is covered with scratches; they have been kindly examined by Dr. Horne, and accepted as glacial. It has been subject to glacial action before or during the deposition of the bed in which it was found. The glaciation which scratched this mammoth tusk is the oldest yet determined in Scotland. Most of the mammoth remains in England appear to be pre-Mousterian and pre-Chalky Boulder Clay. It was first associated with the reindeer in England in the Mousterian, and they occur together in Switzerland in the Riss. The boulder clay overlying the Arctic shell bed and mammoth-reindeer bed at Kilmaurs is probably upper Mousterian, and contemporary with the upper Chalky Boulder Clay and with the beginning of the Wurm.

This period is succeeded in Scotland by bone beds which were well exposed at Cowden Glen, near Neilston and Crofthead, about 15 miles to the S.W. of Glasgow. This stage has two represent-

Digitized by Google

ative localities. At Croftamie near Drymen Station, the reindeer was associated with the horse, Urus (*Bos primigenius*), and Irish elk (*Megaceros giganteus*). At Cowden Glen near Neilston, the horse, Urus, and Irish elk were present, but neither reindeer nor mammoth. The absence of the reindeer at Cowden Glen may be accidental, for it appears to have lived on later than this stage in the Clyde Valley and its survival to the Neolithic in the north of Scotland has been established by Drs. Peach and Horne (1917, p. 341). Hence the boulder clay that overlies the bone beds at Croftamie and Cowden Glen may be on the same horizon.[10] If, however, the Cowden Glen bone bed dates from after the departure of the reindeer from southern Scotland, its overlying boulder clay would be the fourth in the western Scottish Lowlands.

The uppermost boulder clay of the Clyde area passes up gradually into shell beds with a rich Arctic fauna and remains of the reindeer. The Arctic shell bed is associated with the hundred foot beach, which is probably but little, if any, later than the Magdalenian.

The next definite horizon is that of the twenty-five foot beach which is Azilian or later Paleolithic or early Neolithic. The Scottish Azilian is represented by the Oban caves, which were in occupation later than the formation of the 50 ft. beaches, and the deposits investigated by Mr. Bishop at Oronsay and by Mr. Ludovic Mann in Loch Sunart. The twenty-five foot beach in Glasgow yielded numerous dug-out canoes, with one of which at St. Enoch's Square Church, was found a Neolithic implement.

Some members of the Azilian fauna, such as the red deer and *Bos longifrons* are still living in Scotland; but the Urus disappeared before Roman times.

Some of the moraines in the S.W. of Scotland extended below the limit of the glacial submergence represented by the boulder clay. Those moraines probably correspond to the upper glaciation of the reindeer period; for though some glaciers in the Highlands and the Glen Rosa glacier in Arran may have been contemporary with the hundred foot beach, the main moraines were probably earlier than that beach, which was certainly later than the upper boulder clay.

The balance of evidence shows that the Neolithic climate was warmer than the present, for the oak trees used for the Clyde canoes and the contemporary hazel nuts were larger than grow in Scotland now. Yet according to Mr. Hinxman (1892) glaciers

Digitized by Google

in Ross reached the sea-level in Neolithic times, for he claims that they flowed over the 50 foot beach at Annat on Upper Loch Torridon. The 40 foot beach at Loch Eil was later than the moraines (A. Geikie, 1863, p. 169) and the evidence for the Neolithic age of the Annat moraines is not convincing. The Hinxman described the underlying beach material as marine alluvium. It is well shown both at his section and at an exposure on the northern side of Glen Torridon, east of a cottage near the junction of the Annat road; in both the material is false-bedded loam and sand with some peaty layers, and bog iron ore. I could see in it no marine material; it appears to be a river drift. The moraine has cut into this bed so that the level of the original surface is uncertain. If it were marine it might be a dissected fragment of the hundred foot beach, a patch of which is marked on the Geol. Survey Map (sheet 81, 1896), three and a quarter miles to the west above Loch Damh. The existence of this patch disproves the view that the lochs of western Ross were occupied by ice at the time of the hundred foot beach, which was thereby restricted to the outer coast; the sea extended at least to nearly the head of Loch Torridon. The rarity of the hundred foot beach in that loch would suggest that its absence in other places is due to denudation and not to non-deposition.[10]

[10] This glaciation was probably as extensive as the earlier, which is marked as 'major' because of the greater effect due to its action on an unglaciated country. The middle boulder clay of Scotland was probably contemporary with the major glaciation of England.

Digitized by Google

Summary of Correlation of the Scottish Glacial Series.

Characteristic Mammals.	Implements.	Continental Glaciation.	English Deposits.†	Scottish Representatives.
Bos primigenius, Horse, Irish Elk.	Neolithic.		Neolithic.	25 ft. beach.
	Palaeolithic Upper-Azilian.			Caves below 50 ft., etc.
Reindeer	Magdalenian, Solutrian, Aurignacian, Up. Mousterian	Wurm	Mountain Moraines and Arctic bed of Lea Valley.	50 ft. beach, Arctic shellbeds, 100 ft. beach, Last Moraines.
			Upper Chalky B.C.	Uppermost B.C. over Cowden, Glen and Croftan bone beds.
Mammoth and Reindeer.	Mid.—Low Mousterian	Riss	Lower (Kimeridgic) Chalky B.C. Brick-earth and gravels.	Mid. B.C.‡ Kilmaurs Bed Lower B.C.‡
Mammoth.	Low.—Acheulian		Lower B.C. of Stour Valley, and Norfolk Brick-earth.‡	Major glaciation.
Elephas antiquus (Straight-tusked Elephant).	Chellian.	Interglacial after Mindel.	Cromer Forest Bed.	——

† For advice in regard to the English succession I am much indebted to Prof. Boswell.
‡ Both with northern rocks.

Digitized by Google

References.

Chambers, R.
1855. On the Great Terrace of Erosion in Scotland, and its Relative Date and Connection with Glacial Phenomena. Edin. New Phil. Journ. Vol. I, No. I, pp. 103-6.

Geikie, A.
1863. On the Phenomena of the Glacial Drift of Scotland. Trans. Geol. Soc., Glasg., I, pt. 2, pp. viii, 190, I pl.

Geikie, A.
1901. The Scenery of Scotland . . . ., 3rd edit., pp. xx, 540, 5 pl.

Geikie, James.
1894. The Great Ice Age, and its Relations to the Antiquity of Man. 3rd. edit., xxviii, 850 pp., 19 pl.
1914. The Antiquity of Man in Europe, xx, 328 pp., 25 pl.

Greenly, Edward.
1907. The Geology of Anglesey. Mem. Geol. Surv., I, xi, 388 pp., 26 pl.; II, pp. 388-980, 52 pl.

Gregory, J. W.
1907. A Glaciated Rock Surface at Lugton, North Ayrshire. Trans. Geol. Soc., Glasg., xiii, pp. 10-18, pl. i, 11.
1915 (1). Geology of To-day. xv, 328 pp., 23 pl.
1915 (2). Geology of the Glasgow District. Proc. Geol. Assoc., xxvi, pp. 151-165.
1916. Corries, with Special Reference to those of the Campsie Fells. Trans. Geol. Soc., Glasgow, xv, pp. 62-76, 2 pl.

Gregory, J. W., and Tyrrell, G. W.
1924. Excursion to Arran. Proc. Geol. Assoc., xxxv, pp. 401-23.
See also Renwick, J.

Hinxman, L. W.
1893. On the Occurrence of Moraines later than the 50 foot Beach in the North-West Highlands. Trans., Edin. Geol. Soc., vi, pp. 249-51, pl. xi.

Jolly, William.
1868. On the Evidences of Glacier Action in Galloway. Trans. Edin. Geol. Soc., Vol. I, 1868, pp. 155-85, pl. 6.

Lewis, H. Carvill.
1894. Papers and Notes on the Glacial Geology of Great Britain and Ireland. xvi, 469 pp., 10 maps.

Osborn, H. F. and Reeds C. A.
1921. Old and New Standards of Pleistocene Division in Relation to the Prehistory of Man in Europe. Bull Geol. Soc. Amer., Vol. 33, pp. 411-90.

Peach, B. N., and Horne, J.
1917. The Bone-Cave in the Valley of Allt nan Uamh (Burn of the Caves), near Inchnadamff, Assynt, Sutherlandshire, Proc. Roy. Soc., Edinb., xxxvii, pp. 327-49, 4 pl.

Priestley, R. E.
1923. British (Terra Nova) Antartic Expedition, 1910-13, Physiography, Robertson Bay and Terra Nova Bay Regions, x, 87 pp., 19 pl., 3 maps.

Digitized by Google

Reade, T. Mellard.
1897. Geological Observations in Ayrshire. Proc. Liverpool Geol. Soc. VIII, pp. 104-29, pl. 8.
Ritchie, James.
1920. The influence of Man on Animal Life in Scotland. xvi, 550 pp., 9 pls. 6 maps.
Renwick, J., and Gregory, J. W.
1907. The Loch Lomond Moraines. Trans. Geol. Soc., Glasgow, XIII, pp. 45-55.
Smith, J.
1898. The Drift of Glacial Deposits of Ayrshire. Trans. Geol. Soc., Glasg., XI, Suppl. XII, 134 pp., 1 pl.
Wills, L.
1924. The Development of the Severn Valley in the Neighbourhood of Iron-Bridge and Bridgnorth, Q.J.G.S., LXXX, pp. 274-314, pl. xxii-xxiii.
Wright, W. B.
1914. The Quaternary Ice Age. xxiv, 464 pp., 23 pl.

Digitized by Google

No. I.—The Structure of South Knapdale (Argyll).

By W. J. Mc Callien, B.Sc., Geology Department, Glasgow University.

CONTENTS.

		PAGE.
I.	Introduction	377
II.	District Described	378
III.	Stratigraphy, ...	
	Tables of rock groups.	
	Types of rocks developed in groups.	
IV.	Structure, ...	
	The base of the Ardrishaig group.	
	Changes in the stratigraphy from north-east to south-west.	
	Previous views on the Erins Quartzite.	
	Comparison of structures in Cowal and South Knapdale.	
	Structure of the Erins Quartzite.	
	The Limestone problem.	
	Comparison of the Stronchullin Phyllites and Ardrishaig Phyllites.	
	Structure of the Stronchullin Phyllites.	
V.	Metamorphism,	
	The work of (*a*) Hill (*b*) Bailey and (*c*) Tilley.	
VI.	Conclusion.	
VII.	Selected References.	
VIII.	Appendix: Explanation of Diagrams.	

I. Introduction.

In Part 2 of the present volume of the *Transactions* of this Society [1925 (1), pp. 233-263], I published a short paper compiled from a series of notes collected in the Tarbert district; in the present paper I submit a series of diagrams illustrating the structure of the

Digitized by Google

district to the north-west of Tarbert—a district hitherto largely neglected by investigators of South-West Highland problems. These notes and diagrams have been made during the progress of more extensive work on the detailed geology of Kintyre.

This paper has been compiled without taking into account the structure of the peninsula of Kintyre, although I believe that a final statement of the structure of South Knapdale is impossible until the structure of the northern part of Kintyre forming the south-eastern shore of West Loch Tarbert is definitely known. Some time must elapse before the results of my investigation of the latter district can be made public as I find it necessary to re-map several horizons, particularly the Green Beds.

II. District Described.

South Knapdale is the oval-shaped tract of country between West Loch Tarbert and Loch Caolisport. These two lochs run into the Sound of Jura on either side of the headland between Kilberry Point and Ardpatrick Point. This headland is disected by Loch Stornoway, a small loch running parallel with the two larger lochs mentioned above. To the north-east the opposite extremity of the oval is truncated by the straight north-to-south coast of Loch Fyne. The hills are higher than any found in Kintyre, the area to the south of Tarbert, and the range of Sliath Ghaoil[1] running from north-east to south-west forms the back-bone of South Knapdale and the major axis of the oval. Other ridges running in the same direction are well-marked on the south-eastern side of Sliath Ghaoil where epidiorite in particular forms outstanding features. A prominent escarpment of schist and limestone is seen on the north-western side of Glen Ralloch.

As defined here South Knapdale includes two ranges of hills, of from 500 to 600 ft. in height, between Tarbert and Glen Ralloch but this area will not be dealt with in the present paper, though it will be found necessary to trespass into the neighbouring country of Cowal. (For map see page 379.)

III. Stratigraphy.

The rocks included in the area are arranged in the following table from north-west to south-east.

[1] Sliabh Gaoil of Sheet 28.

Digitized by Google

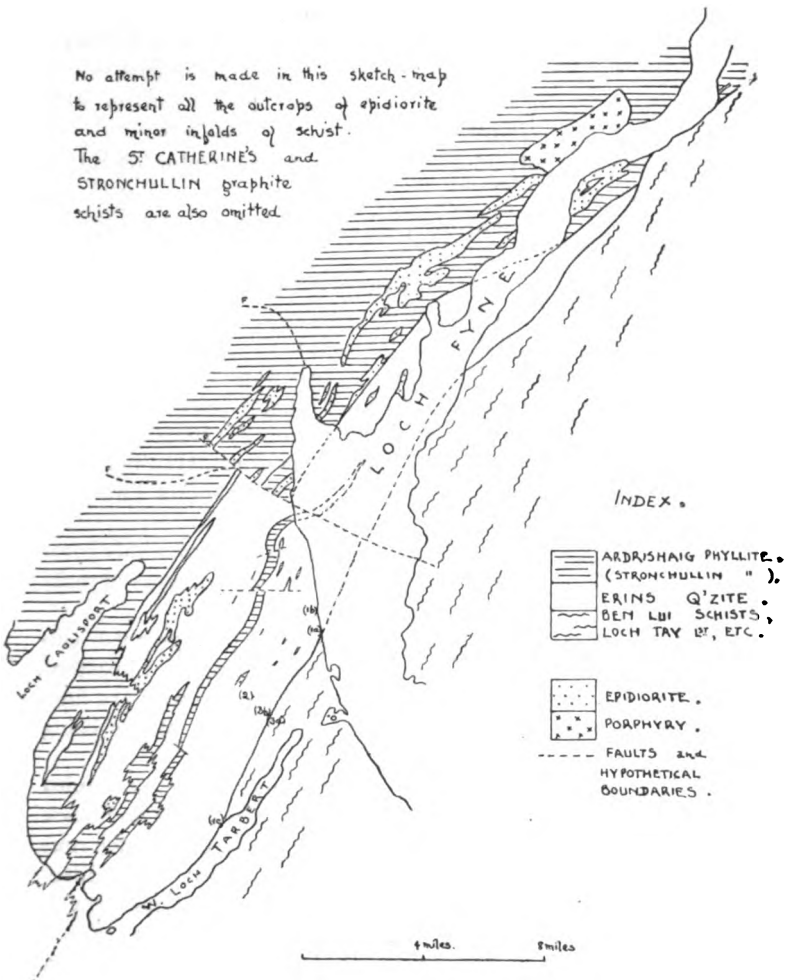

No attempt is made in this sketch-map to represent all the outcrops of epidiorite and minor infolds of schist. The St CATHERINE'S and STRONCHULLIN graphite schists are also omitted.
LOCH FYNE
Loch Caolisport
Loch Tarbert
INDEX.
ARDRISHAIG PHYLLITE.
(STRONCHULLIN ").
ERINS Q'ZITE.
BEN LUI SCHISTS,
LOCH TAY LST, ETC.
EPIDIORITE.
PORPHYRY.
FAULTS and HYPOTHETICAL BOUNDARIES.
4 miles.
8 miles

Fig. 25.

Digitized by Google

Ardrishaig group.	Ardrishaig Phyllites. Erins Quartzite containing the Stronchullin Phyllites.
Ben Lui group.	St. Catherine's Graphite Schists in Cowal. Ben Lui Schists or Stonefield Schists.
	Loch Tay Limestone. } South-east of Glen Green Beds. } Ralloch.

This is the generally adopted sequence but the following is that used in this paper.

Ardrishaig group.	Ardrishaig Phyllites (with Stronchullin Phyllites).
Ben Lui group.	St. Catherine's Schists. Ben Lui Schists, etc. as above.

The only difference in the two tables is in the position and interpretation of the Stronchullin rocks. Most workers in this part of the country believe that these form an integral part of the Erins Quartzite division, and this was my original belief [1925(1) p. 246], but I now consider that the STRONCHULLIN PHYLLITES represent an infold of the southern members of the ARDRISHAIG PHYLLITE group.

Before examining the evidence put forward to prove this point it will be necessary to say a word or two about the types of rocks developed in the subdivisions set out above.

The *Ardrishaig Phyllites* are a series of pale greenish calcareous phyllites with dark grey mica schists. Limestone and quartzite bands are common. The quartzites are fine-grained and very finely bedded—the bedding planes being covered with soft silvery mica.

The *Stronchullin Phyllites* consist of quartzose schists, mica schists, grey phyllites, leaden coloured mica schists and black graphitic phyllites. In a gorge section in the burn which runs north of west past Forest the rocks consist of phyllites varying from black to pale silvery micaceous schists through reddish and green varieties. Iron and copper pyrites and iron carbonate are abundant. A quartz-biotite schist from the phyllites north of Carse shows, under the microscope, bands of irregular quartz grains separated by folia of muscovite, biotite, and chlorite and contains several large and well-formed garnets which in places are decomposing to chlorite.

Digitized by Google

The *Erins Quartzite* is usually defined as a fine-grained slightly calcareous quartzite but quartz schists, grits and phyllitic mica schists are also abundant. It differs from the thin quartzite bands of the Ardrishaig Phyllites in showing characteristic massive bedding.

A slide of the typical rock from the shore section north of Meal Mor shows abundant quartz grains with occasional plagioclases. Foliation is indicated by a slight elongation of the grains and by the presence of much scattered chlorite. Minute garnets are common. In the phyllites from here dark brown mica is abundant as a late metamorphic mineral. In a slide of phyllitic mica schist from Abhainn na Cuile epidote and biotite both occur as metamorphic minerals and define a strain cleavage running right across the one defined by the white mica.

The portion of South Knapdale included in the 1″ sheet 20 of the Geological Survey of Scotland is composed entirely of quartzite, coarse grits, phyllites and limestones belonging to the Erins group. In the map it is divided into two parts, that to the north-west being coloured quartzite, that to the south-east schist and limestone.

St. Catherine's Graphite Schist. This subdivision of the Ben Lui group does not occur in South Knapdale. From the type locality it consists of dark grey schists associated with limestone and calcareous siliceous schist.

The *Ben Lui Schists or Stonefield Schists* consist chiefly of garnetiferous mica schists, chlorite schists, albite schists and grits. A fairly thick limestone, the *Ashens Limestone* stretches from Loch Fyne to West Loch Tarbert. A band of massive quartzite occurs within the schists on the south-eastern slopes of Cruach Gardhoire. A slide of this rock shows large grains of quartz and albite separated into bands with biotite, chlorite and epidote. It will be pointed out later that from the appearance of this in the field it most likely belongs to the Erins Quartzite.

The *Loch Tay Limestone* is a grey crystalline limestone with calcareous schists.

The *Green Beds* contain chlorite-epidote schists, quartz schists, albite schists and grits.

Digitized by Google

IV. Structure.

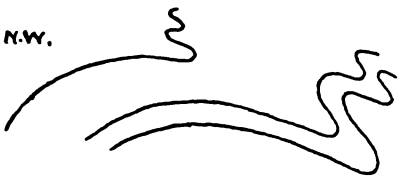
The lower limit of the Ardrishaig group in Cowal was originally taken by Clough at the horizon of the St. Catherine's Graphite Schists. Bailey (1922, p. 100), however, guided by the improbability of green schists continuing north-west across the thrust at the base of the Loch Awe Nappe shifted the northern boundary of the Garnetiferous Mica Schist group so that all the green schists would be included within the Cowal Sequence. Later Tilley [1925(2), p. 109], on quite different grounds, showed the correctness of Bailey's interpretation.

If the St. Catherine's Graphite band were continued to the south-west then, as stated by Clough (1911, p. 37), it would form an important stratigraphical horizon. But it has not been found to the south-west and doubtless does not exist. In this direction there is a marked change in the stratigraphy and the Erins Quartzite makes its appearance and attains its maximum development in South Knapdale. As already stated, this group of quartzites is divided into two by the Stronchullin Phyllites which contain a band of graphite mica schists somewhat similar to the St. Catherine's band. Correlating the St. Catherine's with the Stronchullin Phyllites, Bailey (1913, p. 300) was at one time of opinion that the Erins Quartzite belonged half to the Ardrishaig group and half to the Ben Lui group but is now satisfied that it belongs entirely to the former. Bailey also believed originally that the Stronchullin Phyllites did not mark the centre of a fold. In his latest writings, however, he has left the question open. The evidence as put forward here leads me to believe that they do mark the centre of an isoclinal fold.

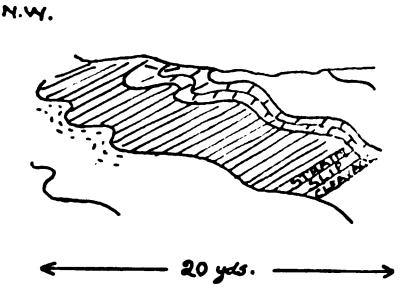
In Cowal it is well-known that there is an upward structural succession as we proceed north-west from the flat-belt of the Cowal anticline. On the western shore of Loch Fyne, in the area at present under consideration, this statement requires modification, though on the whole it still remains true. North of Glen Ralloch, the north-western part of the Ben Lui Schists rests upon the south-eastern margin of the Erins Quartzite, as indicated by the dip to the south-east. Not until we reach as far north as the Stronchullin Phyllites does the Erins Quartzite assume anything like the north-westerly dip which prevails throughout the sequence in Cowal. This change in dip in South Knapdale is sufficient to account for an increased width across the outcrop of the Erins

Digitized by Google

N. LODGE, STONEFIELD,
showing low dip to north of EAINS QUARTZITE.
(a).



Diagrammatic representation of first shore section north of MEAL MOR.
(b).



Western shore of TORINTURK BAY.
Low dip of EAINS QUARTZITE GAITS and LIMESTONE to south-east.
(c).

Fig. 26,

Digitized by Google

Quartzite. For this reason also, the Ben Lui Schists are narrower in South Knapdale than in Cowal because in the former locality they pass through the vertical before dipping to the south-east; in the latter they dip continuously to the north-west. These schists are vertical in the hills north of Tarbert and south of Glen Ralloch while north of Glen Ralloch they dip to the south-east; The contrast in dips on either side of Glen Ralloch is so marked that it led me to insert a fault between them.

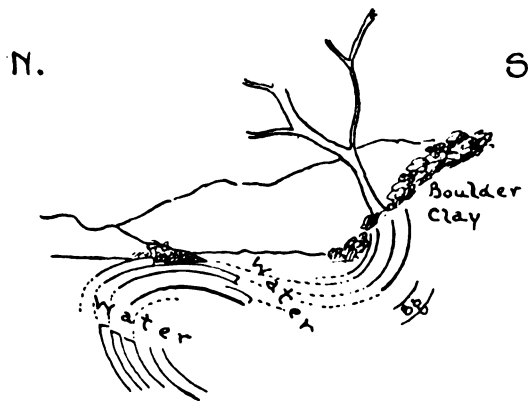


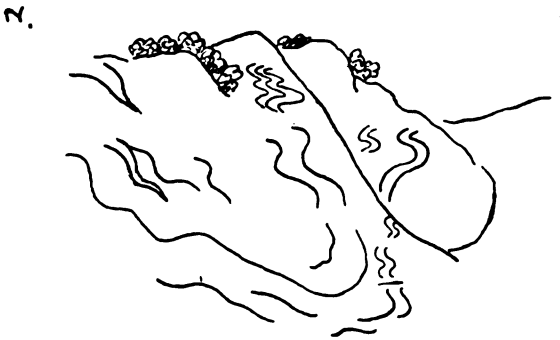
Fig. 27.—Fold in Erins Quartzite, Allt Mor.

In my previous paper [1925(1), p. 247], I pointed out that there were a series of schists north of the Survey's northern boundary of the Ben Lui Schists which belonged to the latter group. A considerable distance within the new boundary of these schists is a well-marked band of quartzite which no doubt was originally taken as representing the true beginning of the Erins group. This quartzite is typical of the Erins Quartzite and is well exposed on the southern face of Cruach Gardhoire. Here the structure of the band is synclinal and I consider that it represents *a core of the main quartzite overfolded within the Ben Lui Schists* (fig. 28).

The structure of the Erins Quartzite is indicated by the series of diagrams taken chiefly from coast sections and from the hill face east of the Abhainn nan Gillean and north of Cruach Gardhoire (*i.e.* from the hill east of that part of the Abhainn nan Gillean which in sheet 28 is called the Abhainn na Cuile).

Digitized by Google

Fig. 26, from the coast of Loch Fyne immediately north of Meal Mor[1] is most instructive. It shows a series of quartzites and



Core of ERINS QUARTZITE within STONEFIELD SCHISTS South side of CRUACH GARDHOIRE.

ERINS Q'ZITE, N. of GLAC NA FHEADAIN.

Fig. 28.

quartz-schists in fairly large almost isoclinal folds, the axial planes of which are inclined to the south-east, and somewhat similar folds

[1] Milmore Cottage of sheet 29.

Digitized by Google

are indicated in figs. 27 and 28. As a rule at most places on the eastern coast of South Knapdale the Erins Quartzite dips gently to the north-west. On the western shore of Torinturk Bay[1] in West Loch Tarbert it dips at low angles to the south-east and is crossed by a marked strain slip to the north-west (fig. 26c). Fig. 29 represents these folds incorporated in one diagrammatic section from the south of Sliath Ghaoil to West Loch Tarbert.

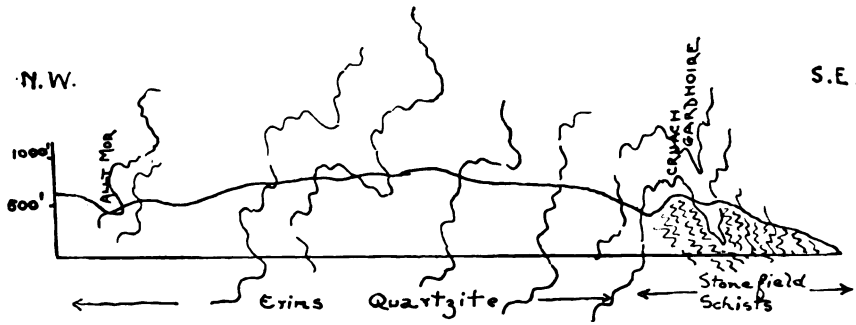


Fig. 29.—Section across the Erins Quartzite (north of Conach Gardhoire), showing core within Stonefield Schists, and incorporating the other structures illustrated.

The limestones in the south-eastern part of the Erins Quartzite may possibly represent the Ashens Limestone brought north-west by folding. I believe they are repetitions by folding of a limestone within the Erins group. The rocks associated with the limestones are gritty quartz schists, more massive than anything within the Ben Lui Schists and not associated with as much micaceous schist as one would expect if they were folded representatives of the Stonefield and Ashens rocks. Hill (1911, pp. 35-36) believed that on account of their gritty character the rocks occurring with the limestones from Torinturk westward should be put into the Stonefield group, the northern boundary of which would therefore swing westward past Ardpatrick and between Ardpatrick and Loch Stornoway.

Thus he states,

" Notwithstanding, however, the somewhat similar lithological facies represented by the two groups in the area through which no stratigraphical boundary

[1] Torinturk Bay is the bay south-west of Barr Mor and east of Eilean Eoghainn, Rhu, Kintyre (sheet 28).

Digitized by Google

has been drawn, it is possible to define broadly the limit of a marginal zone in the portion coloured as quartzite, which in its gritty character more closely approaches the type of the Stonefield Schists. In the description of the latter group it has been shown that its dominant feature is its pebbly character, whereas the adjoining Erins Quartzite division is of finer texture with only subordinate grit bands. Various parallel limestone outcrops on the two sides of Lochan Liath are situated in a zone of schists with a prevailing pebbly structure. It has been observed that to the south-west of the Abhainn Ghillean, the limestone outcrops increase in number in a manner which we regard as the result of folding, so that they extend still further to the west into the tract that has been coloured as quartzite. Now the belt in which these limestones occur contains as great a preponderance of grit bands as do the Stonefield Schists to the north-east, so that the limestone belt, which beyond the Abhainn Ghillean bulges to the west, is flanked on its outer margin by a zone of grits which shares in that bend. Thus, commencing at the eastern margin of the map, we find a marked development of gritty schists forming the crags of Cruach Gar-dhoire and overlooking the river for half a mile to the south-west. They occupy an horizon about half a mile in width adjoining the Ashens limestone belt. Beyond the Abhainn Ghillean these grits swing to the westward past the southern slopes of Cruach Chaorunn Beaga, and from thence to the south-west to Gleann Fithich. They thus enclose the zone, extending westward from West Loch Tarbert, in which the limestone outcrops occur. The edge of this grit zone extends a quarter of a mile beyond the most westerly limestone outcrop in Eas a' Chais, but considerably more than that distance in the curve below Cruach Chaorunn Beaga. Probably, therefore, the western margin of this pebbly zone represents approximately the boundary between the Stonefield and Erins divisions."

Though gritty the above rocks are different in field characters from the gritty bands in the Stonefield Schists. Gritty rocks are found practically everywhere with the Erins Quartzite and are especially well seen with the massive quartzites around Loch Bhaillidh and in Cruach a' Bhaillidh to the north. Limestones in small bands occur about 3½ miles further west of north of Loch Bhaillidh and on the shore south of Keppoch Point.

From the descriptions of the Stronchullin Phyllites given in this paper and in others dealing with the same rocks, it seems that they are different from the Ardrishaig Phyllites. But we must remember that the outcrop of the latter is wide and only a general statement of the dominant varieties of schists is given. The Stronchullin band is relatively thin and to match it with Ardrishaig phyllites we must consider these in considerable detail, which is the purpose of the following paragraph.

The characteristic rock of the Stronchullin Phyllites is perhaps a quartzose schist rather than a phyllite, with apparently a more advanced type of metamorphism than the Ardrishaig group to

Digitized by Google

the north and north-west. Correlation of the two has therefore not been attempted hitherto. Though on the whole the phyllites around Ardrishaig are grey-green and fine-grained, characteristic sections to the south between the Erins Quartzite and Brenfield Point or even further north closely resemble the Stronchullin Phyllites. Here we get abundant bands of quartzite and quartz and mica schists in the phyllites. North of Brenfield Point green phyllites are common and usually closely connected with epidiorite sills. Such rocks also occur within the Stronchullin Phyllites north-west of Carse. The graphitic band within these phyllites may be looked upon as a local variation of the normal rock, and if not so, it can easily be matched with similar bands north of Brenfield Point. The isoclinal folding of the Stronchullin Phyllites is admirably seen in the sections north-east and south-west of Loch Bhaillidh.

Coincident with the dying out of the south-eastern band of Stronchullin Phyllites a larger fold lets in a wider outcrop to the north-west at the north-eastern end of the north coast of Loch Stornoway. This band is within one mile of the Ardrishaig Phyllites, the southern margin of which has been steadily advancing south-eastward and I believe that the two, *i.e.* the Stronchullin Phyllites and Ardrishaig Phyllites, come into contact and join up a short distance from the shore between Kilberry Head and Loch Stornoway.

Likewise, as these folds are pitching to the south-west the Stronchullin Phyllites die out in Loch Fyne to the west of Otter. Though the major folds are pitching south-westward it is not uncommon to find minor folds which pitch in an opposite direction, e.g. in the Erins Quartzite on the shore of Torinturk Bay, small folds pitch to the north-east. Similar changes of pitch between minor and major folds have been noticed by Clough in Cowal.

V. Metamorphism.

This paper is intended primarily as a description of the several diagrams of the structures met with in South Knapdale, but it seems to me that a few remarks upon the general metamorphism of the area will not be out of place at this stage.

Firstly, let us consider briefly the work of three investigators, J. B. Hill, E. B. Bailey and C. E. Tilley. I will not deal in any detail with their work but will only summarise their results.

Digitized by Google

Hill in his work on the Progressive Metamorphism in the Region of Loch Awe points out that the rocks in the country with which we are now dealing show a decreasing metamorphism when traced north-west across their strike from the axial belt of the Cowal Anticline south of Tarbert. This fact has previously been pointed out for the Cowal area in the Cowal memoir of the Geological Survey.

Bailey gives (1923, pp. 317-331) a more detailed account of the metamorphism of the S.W. Highlands in a paper published shortly after his " Structure of the South-West Highlands." In it he divides his metamorphic scale into three, with two alternatives in the third grade:—

(1) Mica Inconspicuous.
(2) Mica Conspicuous.
(3*a*) Mica with Garnet.
(3*b*) Mica with Albite.

and he finds that there is a vague agreement between the outcrops of these successive metamorphic zones and his structural zones. Thus in northern Kintyre the schists contain mica with albite. (This is not shown in Bailey's map of the zones and is inserted by the present writer). Then in South Knapdale comes the garnet horizon which has hitherto been looked upon as practically absent on the western side of Loch Fyne, but a glance at the description of rocks under Stratigraphy in this paper, in conjunction with my paper on the Tarbert District, will show that garnetiferous rocks extend from the south-east of Tarbert in the Beinn Bheula group upwards through the Green Beds, Loch Tay Limestone, Ben Lui Schists and Erins Quartzite. Bailey, too, thinks that Clough is justified in attributing this high degree of metamorphism which is characteristic of the axial belt in Cowal and south of Tarbert to the greater depth of cover which erosion in this position has since removed.

North-west of the mica-with-garnet zone is the zone of conspicuous mica which stretches up to and into the Erins Quartzite. Microscopic examination of these rocks reveals garnet also, as metamorphic mineral. Finally comes the greater mass of quartzites and phyllites belonging to the Erins and Ardrishaig groups in which mica does occur but is inconspicuous.

Tilley's work is the latest dealing with the metamorphism of the Southern Highlands and has been a continuation to the south-west of the work which was begun by Barrow in the Central and Eastern

Digitized by Google

Highlands. Strictly, his paper has little direct connection with South Knapdale but it is impossible to consider the metamorphism

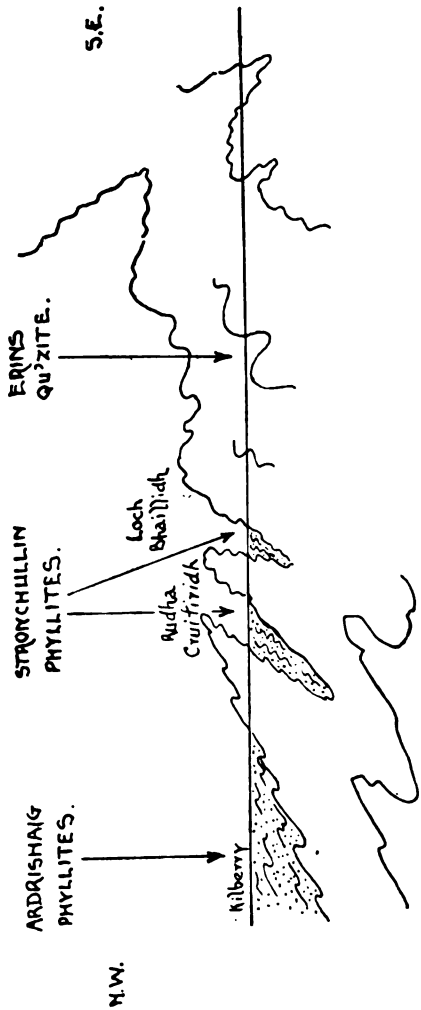


Fig. 30.—Section from Kilberry to West Loch Tarbert.

of this area without consideration of the results which he has obtained in neighbouring districts.

Digitized by Google

His metamorphic zones are

(*a*) Zone of Chlorite.
(*b*) Zone of Biotite.
(*c*) Zone of Almandine (garnet).

Keeping to the western shore of Loch Fyne (*a*) includes all the argillaceous rocks around Skipness. In Cowal and elsewhere it includes the rocks which are a continuation of the argillaceous rocks close to the Highland Boundary Fault. From Port Leathan north to Tarbert (*i.e.* within the Beinn Bheula group) comes the zone of brown biotite, and from Tarbert north through the northern margin of the Beinn Bheula group, Green Beds, Loch Tay Limestone and Ben Lui Schists is the zone of almandine. Judging from the small size of the garnets in the section from Port Leathan to Auchalick (Cowal area) Tilley thinks that only the edge of the zone is truncated by the shore. He goes no further north in South Knapdale than the Ben Lui Schists but on the Cowal side of Loch Fyne he follows north-west of the garnet zone with another band of brown biotite. In the north-east of the area included in Tilley's map the garnet zone is cut off by lowly metamorphosed Ben Lawers Phyllites while in the neighbourhood of St. Catherine's the strongly garnetiferous Ben Lui Schists end abruptly against the Ardrishaig Phyllites, which along this part of the coast are in a low state of metamorphism. Tilley records garnets for some distance on the northern side of the head of West Loch Tarbert. In my previous paper I stated that I had found garnets still further north-west and garnets have been shown in the present paper to occur in the Stronchullin Phyllites. Moreover Tilley is of opinion that albite has no metamorphic significance at all.

VI. Conclusion.

As has already been stated the main purpose of this paper is to describe the rock structures which have led me to believe that the appearance of two discontinuous bands of phyllite within the Erins Quartzite of South Knapdale can be truly explained by the theory that they are infolds of the more important Ardrishaig Phyllites to the north-west. Additional evidence has also been furnished regarding the metamorphic zones of the district.

Digitized by Google

Fig. 31.—Generalised Section across Loch Awe Group and Ardrishaig Group. North-Western Part after Geol. Survey.

6. Volcanic Rocks
5. Black Slate and Limestone } Loch Awe Group.
4. Quartzite

3. Ardrishaig Phyllites
2. Erins Quartzite } Ardrishaig Group.
1. Ben Lui Schists

Digitized by Google

I have to express my indebtedness to Mr. E. B. Bailey for his helpful criticism of the manuscript of this paper.[1]

VII. Selected References.

1897. W. Gunn, C. T. Clough, and others—"The Geology of Cowal," Mem. Geol. Surv. Scotland.

1899. J. B. Hill—"On the Progressive Metamorphism of some Dalradian Sediments in the Region of Loch Awe," Q.J.G.S., lv, p. 470.

1905. C. T. Clough, J. B. Hill and others—"The Geology of Mid-Argyll," Mem. Geol. Surv. Scotland.

1911. B. N. Peach, C. T. Clough, E. B. Bailey, J. B. Hill and others—"The Geology of Knapdale, Jura and North Kintyre," Mem. Geol. Surv. Scotland.

1913. E. B. Bailey—"The Loch Awe Syncline (Argyllshire)," Q.J.G.S., lxix. p. 280.

1922. E. B. Bailey—"The Structure of the South-West Highlands of Scotland," Q.J.G.S., lxxviii, pt. 2, p. 82.

1923. E. B. Bailey—"The Metamorphism of the South-West Highlands' Geol. Mag., lx, No. vii, p. 317.

1925.[1] W. J. McCallien—"Notes on the Geology of the Tarbert District of Loch Fyne," Trans. Geol. Soc., Glasgow, xvii, pt. ii, p. 233.

1925.[2] C. E. Tilley—"A preliminary Survey of Metamorphic Zones in the Southern Highlands of Scotland," Q.J.G.S., lxxxi, pt. i, p. 100.

VIII. APPENDIX: EXPLANATION OF DIAGRAMS.

These diagrams form a progressive and connected series.

Fig. 25 is a general map of the geology of South Knapdale and neighbouring districts, showing only the main subdivisions of the metamorphic rocks. The localities in which occur the rock structures illustrated in figs. 26-28 are indicated by numbers corresponding to the numbers of the diagram.

Fig. 26 (1 on map) contains three sections of the Erins Quartzite, showing dips to the north-west and south-east and the types of folding developed. (*a*) and (*b*) are taken from the coast of Loch Fyne at North Lodge, Stonefield and Meal Mor respectively; (*c*) is taken from the western shore of Torinturk Bay, five and a half miles from the head of West Loch Tarbert. (*a*), (*b*) and (*c*) are drawn to the same order of scale.

Fig. 27 (2 on map) is a burn section in Allt Mor, a north-east—south-west tributary of the Abhainn na Cuile (continuation of Abhainn nan Gillean).

[1] Mr. Bailey pointed out the desirability of verifying that the rocks on either side of the Stronchullin Phyllites are the same as those to the south-east of the Ardrishaig Phyllites. Since this paper was written I have begun an examination of the coastal section from Kilberry Head southward with a view to carrying out Mr. Bailey's suggestion.

Digitized by Google

Fig. 28 (3 on map) contains two diagrammatic sketches of folds within the Erins Quartzite. The upper one is from the south-western slopes of Cruach Gardhoire and represents the core of Erins Quartzite within the Ben Lui Schists.

The lower diagram represents one of many more or less similar structures from the hillside north-east of the Abhainn na Cuile, between Glac na Fheadain (unnamed on one inch map) and the tributary running south-west from Loch Chaoruinn.

Fig. 27 and the two diagrams on Fig. 28 are incorporated in one section in Fig. 29. This section includes that part of South Knapdale between West Loch Tarbert and Allt Mor, shows the south-easterly dip of the Ben Lui (or Stonefield) Schists with infold of Erins Quartzite on Cruach Gardhoire (fig. 3) and the folding of the Erins Quartzite as shown in the previous diagrams.

Fig. 30 includes Fig. 29 plus the country as far north-west as Kilberry, crosses the two outcrops of the Stronchullin Phyllites and illustrates my interpretation of their structure.

Fig. 31 gives a general idea of the position of the rocks with which this paper deals, in the well-known Loch Awe Syncline. It is a continuation southward across South Knapdale of the diagram in the Survey memoir on the Geology of Jura, Knapdale and North Kintyre (p. 60), and shows that the new structures illustrated here may easily be reconciled with those already accepted.

Digitized by Google

UNIV. OF
CALIFORNIA

Digitized by Google

Dorsal (Upper) Surface Aspect.
Rhino. (Coelodonta) antiquitatis.

Ventral (Lower) Surface.
Rhino. antiquitatis.

Digitized by Google

No. III.—Note on a Rhinoceros Bone from the Glacial Sands of Cadder. By W. E. Swinton, B.S.c, F.G.S.

During recent quarrying operations in the glacial sands near the canal, at Cadder, Bishopbriggs, a mammalian bone was brought to light and presented to the Hunterian Museum, Glasgow University, by the owners of the quarry, Messrs. The Bishopbriggs Sand Quarries Ltd., per the Director, Mr. Hunter Bowie. Through the kindness of Professor J. W. Gregory and Dr. J. Weir the bone was sent to me for examination.

The specimen was found some forty feet below the surface in water-rolled glacial gravel, and bears evidence of water action in that the edges of the bone and the articular facets are quite rounded. Despite this, however, the bone is fairly well preserved and is complete. Its total length is 6¼ inches. The bone is obviously rhinocerine and comparison with other fossil Rhinoceros bones proves it to be the second meta-carpal of the left fore-foot of the Woolly Rhinoceros, *Rhinoceros* (*Coelodonta*) *antiquitatis* Blumenbach.

The Woolly Rhinoceros had a wide range over Europe and Asia, during Pleistocene times, extending even into the Arctic circle, and in England its bones are common in the glacial and river gravels, as well as in the cave deposits. In Scotland, however, its remains appear to be scarce and records of its occurrence are few. Geikie in his "Great Ice Age"[1] refers to the "vague mention" of a Rhinoceros horn being found in the marl at the Loch of Forfar. Ritchie in his "Animal Life of Scotland" does not mention *Rhinoceros* as a Scottish Pleistocene form, and the British Museum, which possesses a large collection of fossil *Rhinoceros* remains, has not a single Scottish example. The occurrence of the present well preserved specimen is therefore interesting, and worthy of record.

[1] Geikie, The Great Ice Age, 3rd Edition, 1894, p. 305; Mem. Wernerian Soc., vol. iv, 1822-3, p. 582; *ibid.* vol. v, 1824-6, p. 573.

Digitized by Google

No. V.—Description of the Sand Deposit at Hungryside, Torrance. By W. R. Flett.

The sand-pit in which the bone described above by Mr. Swinton was found, is located on the east side of the Bishopbriggs-Torrance branch road, a few hundred yards from the main Glasgow-Kirkintilloch road. The bone was found in a pebbly bed about 46 feet from the surface. In this layer the pebbles have been water-rolled.

The deposits, in general, consist of pebbly bands, intercalated with fine and coarser sands. These sands contain fairly well-rounded boulders of Highland, O.R.S., and Carboniferous rocks. A census of fifty of these gave a percentage of 30 for Highlands the remaining 70 per cent. consisting of equal parts, O.R.S. and Carboniferous.

The deposits, in the section examined, are as follows (reading from above downwards):

1. About 18 ins. soil and sub-soil.
2. 30 ins. to 36 ins. pebble bed.
3. About 33 ins. of course sand, split into two branches; the upper (9 ins.) of which thickens to 27 ins., and finally peters out between a pebble band and a layer of fine sand. Intercalated with this course sand series is a 12 in. pebble band, forming with the lower (24 in.) branch of the coarse sand a sort of trough.
4. Below this and down to the pebble bed in which the bone was found, at a depth of 46 ft., is a fairly consistent deposit of fine sand. Below the pebble bed the finer sand continues to level at which the pit is at present being worked.

These sands are being utilised at the present time exclusively for building purposes. The subangular nature of the grains makes them very useful in this particular branch of industry, as it gives a relatively stronger grip for the calcareous matrix.

In this respect, it may be mentioned that marine sands are not so valuable and should be avoided on account of the tendency of mortar made from them to "sweat" owing to thin films of deliquescent salts left on them as a coating after evaporation of the water.

A number of theories have been advanced to account for the formation of such deposits in this district. They have been

Digitized by Google

regarded as (1) Part of the high-level terrace of sands and gravels along the sides of the old Kelvin valley. The elevation of the deposit under consideration corresponds approximately with the elevation of such a terrace. The sand-pit is about 150 to 160 feet above sea-level while the terrace is about 170 feet above O.D. Some authorities, however, consider that the terrace represents the margin of a glacial lake which at one time, occupied part of the Kelvin valley.[1] Mr. Carruthers has advanced the view[2] that the sands and gravels which have filled up the old channel of the Kelvin are pre-glacial. (2) Deposits of sands and gravels in a temporary sheet of water impounded by ice. Sub-glacial rivers opened into this temporary lake, the gravels accumulating at their mouths, while the finer sediments settled down in quieter water at some distance from the ice-front.[3]

It may be remarked here that the intercalations of muds and clays, which are a feature in the sands in the pit only a few hundred yards distant, and worked by the same firm, are almost entirely absent in the pit in which the bone was found. The former pit shows phenomena more closely approximating to those of valleys silted up before the advance of a great ice-sheet, being characterized by intercalations of sands, gravels, mud, and boulder clay, contorted and highly irregular, but with a more or less definite distribution.

The deposits, however, in the pit in which the bone was found, bear evidence of being water-borne. The progressive rounding of the sand grains as they increase in size is diagnostic of water-borne material. The fact that the fossil bone was isolated from the rest of the skeleton suggests that it was carried by running water to the place where it was found. It is difficult to obtain convincing proof of the source of this water. The evidence at present available tallies most closely with the second theory.

Permission to examine the deposits was kindly granted by the director of Messrs. The Bishopbriggs Sand Quarries, Ltd., Mr. Hunter Bowie, who has given every assistance on all occasions. Mr. Bowie, it may be added, encourages his employees to record any interesting find, by giving a bonus to the workman who brings in anything of interest or of scientific value.

[1] The Geology of the Glasgow District. *Mem. Geol. Survey*, 1925, p. 233.
[2] *Ibid*, p. 233.
[3] *Ibid.*, p. 227.

Digitized by Google

No. VI.—Petrography of the Hungryside Sands. By W. Roberts Flett, Geology Dept., Glasgow University.

Analyses of the sands described in the previous paper were made for the most part by mechanical means.

The finer grades of sands are generally analysed by the method of elutriation.

The elutriators employed in these analyses were of the Crooke type (with a modification due to Stadler).

The fine sand, on analysis, gave the following figures:

Grade.	*Percentage by weight.*
Less than .01 mm. diameter (clay)	0.914
Between .01 and .06 mm. diameter	.918
,, .06 and .1 mm. diameter	6.620
,, .10 and .2 mm. diameter	52.530
Greater than .2 mm. diameter	38.810

It will be observed that the bulk of this sample is composed of fine sand according to Prof. Boswell's classification.[1]

The following are the figures obtained for the coarse sand:

Grade.	*Percentage by weight*
Less than .01 mm. diameter (clay)	.5724
Between .01 mm. and .06 mm. diameter (silt)	.2346
,, .06 mm. and .10 mm. diameter	1.3150
,, .10 mm. and .20 mm. diameter	11.6100
,, .20 mm. and .30 mm. diameter	18.9000
,, .30 mm. and .38 mm. diameter	20.0400
Greater than .38 mm. diameter	46.5000

In this analysis more than 84 per cent. of the sample falls under Prof. Boswell's classification of coarse sand.

The pebbly bed, in which the bone was found, was also examined and graded roughly by means of sifting. The pebbles greater than 1 cm. in diameter were removed and the remainder screened in a series of sieves.

[1] Boswell, P. G. H. British Resources of Sands and Rocks used in Glass-making, 1918, p. 13.

Digitized by Google

The proportions were taken, as in the previous case, by weight and the following figures were obtained:

Grade.	*Percentage.*
Less than 3/8 in. diam. but greater than 1/10 in. diam. ..	53.27
,, 1/10 in. ,, ,, 1/30 in. diam. ..	17.82
,, 1/30 in. ,, ,, 1/60 in. diam. ..	16.88
,, 1/60 in. ,, ,, 1/90 in. diam. ..	7.51
,, 1/90 in. ,, ,, 1/100 in. diam. ..	.237
,, 1/100 in. ,, ,, 1/120 in. diam. ..	.510
,, 1/120 in. diam.	4.064

This method of screening is open to the objection that the mesh in most sieves is rectangular, and grains of various diameters from the length of one side to the length of a diagonal pass through, thus giving rise to inconsistency in grade retained or passed through. Grains with diameter less than 1/50 in. should be separated by elutriation.

The sands were also separated into heavy and light crops by means of bromoform, the heavy crop being composed of mineral species with a specific gravity of 2.9 or over, while the light crop had a specific gravity below 2.9.

The percentage heavy residue in the fine sand was about 1.72 by weight.

The percentage heavy residue in the coarse sand was about 3.61 by weight.

The light crop was examined under the microscope, and proved to consist for the most part of quartz and felspar, both of which were somewhat ironstained. This light crop also contained what appeared to be very small particles of an impure coal, coated with a slight film of manganese.

The heavy residue was subjected to a further mechanical separation by magnetic and electro-magnetic methods. The bar-magnet was used for separating the minerals with a magnetic susceptibility approximating to that of magnetite. The remainder was further separated by means of the electro-magnet, the coil-strength of which could be adjusted by varying the resistance and tapping extra turns in the coil. This gave a series of mineral species ranging from moderately magnetic to non-magnetic.

Microscopical examination of the Sands.

Both grades of sands had practically the same suite of minerals though the relative proportions varied. Owing to the nature of

Digitized by Google

the sands and the method of mounting the sand grains, there is always a possibility of some minerals being omitted, but it can be assumed with a fair degree of safety that the minerals continually present or of special importance have been observed.

Cubic.	*Trigonal.*	*Tetragonal.*
Magnetite.	Quartz.	Zircon.
Garnet.	Ilmenite.	
Pyrites.	Haematite.	
	Tourmaline.	
	Calcite.	

Rhombic.	*Monoclinic.*
Enstatite.	Orthoclase.
	Mariposite?
	Chlorite?

(*a*) *Iron Ores.* A feature of the examination of the heavy residues was the large proportion of iron ores present, these ores ranging right through the various degrees of magnetic permeability were magnetite, ilmenite, haematite and pyrites. They were for the most part opaque, except in the case of a few particles of haematite, which were translucent but not sufficiently so for diagnostic purposes with transmitted light. The magnetite and ilmenite compared with the other iron ores were not so abundant as would be expected. The ilmenite was usually associated with its alteration product leucoxene. The pyrites had the characteristic brassy colour, opaque in transmitted light, but showing the characteristic yellow colour in reflected light.

(*b*) *Gamet* is next in abundance to the iron ores. It was pinkish brown in colour and showed anomalous double refraction in most specimens.

(*c*) *Quartz* made up the bulk of the light residue and along with the felspar present showed signs of iron-staining. These two, with very sparsely distributed calcite, made up the light residue. The calcite gave a fairly good partial uniaxial figure.

(*d*) *Tourmaline.* Sparse. Occurred in straight-sided prismatic sections. Intense pleochroism from light yellow-brown to dark-brown.

(*e*) *Zircon.* Only one specimen was observed. It showed the usual characteristic straight-sided crystal section.

(*f*) *Enstatite* occurred as a bottle-green mineral giving a partial positive biaxial figure.

(*g*) *Mariposite?* An emerald-green mineral was observed which was distinctly micaceous in appearance, showing the characteristic

Digitized by Google

platy surfaces. As it was very abundant in the heavy residue and possessed a highly reflecting surface, it was easily separated from the remainder. On examination, the basal section was isotropic or nearly so. It gave a fairly good biaxial interference figure. On being tested with various immersion media it showed a R. I. of 1.63 corresponding to the mean R. I. for the chromiferous mica-mariposite.

(*h*) *Chlorite*? Another green micaceous mineral was noted. It was anisotropic and of somewhat lower R. I. than the mineral described above. Birefringence of a fairly low order. It did not react to any specific microscopical test so it was provisionally named chlorite, whose exact determination in detrital grains is almost an impossiblity, owing to the anomaly of the results obtained from the usual tests.

Digitized by Google

No. VII.—The Petrography of the Clyde Alluvium. By B. Hilton Barrett, M.A., B.Sc., F.G.S., Carnegie Teaching Fellow, Glasgow University.

The construction of new docks has given temporary access to sections in the alluvial deposits of the Clyde. The excavations lie west of the city at Shieldhall, on the south side of the river.

The whole depth of the sand is never available for examination, on account of the constructional methods in use, but a series of fifteen bore records was kindly presented by Mr. David Ferguson F.R.G.S., M.Inst.M.E. These show that the loose deposits vary in depth from 36 feet up to 79 feet. The rock surface on which the sands rest is very variable. No fossils have been found in any part of the alluvium. Sections available for measurement sometimes extend to about 40 feet in depth, but are usually less and at no place has bed rock been seen.

The extremely variable nature of the deposit will be realised from the following sections which lie about twenty yards apart and cover practically the same material.

	I Feet.	II Feet.
Stiff brown clay	8	3
Coarse sand	6	3
Fine grey clay	–	1
Fine sand	6+	12+

The change takes place in the character of fine sand in its exposed upper position at this place. So great is the variation from point to point that no section can be given which is representative of the deposit as a whole. Variation is less noticeable near the present course of the river. Lenticles of clay occur frequently; the grey clays are always thin, but the brown ones sometimes reach a considerable thickness. Both are finely laminated. There is reason to believe that the greatest variation is confined to the upper 30 feet of the deposit, and that below this

Digitized by Google

only two types of sand are present—an upper of fine grade and a lower of coarser grade. Pebble beds are common and generally form the base of the band in which they occur. In the bed of coarse sand in the table this is the case. The pebbles are usually well rounded and have been subjected to a considerable amount of river action. A census of fifty made in one of the beds showed that the majority are derived from Highland sources:—vein quartz 13; schists and quartzites 17; sandstones (mostly Carboniferous) 13; basalt 11; agglomerate 2; shale 1. Coals are frequently seen and fine coaly matter often brings out the false bedding in the sands of the upper parts. The high percentage of Highland rocks suggests that they have been washed out of the boulder clay. The interval between the boulder clay and the alluvium is probably quite long enough to account for the degree of rounding attained. The pebbles are always heavily iron-stained. Their presence at the base of the bands probably indicates changes in the course of the river in its upper parts and possibly increased rainfall.

The heavy residues are dark in colour. A point which may be worthy of mention is that the magnetic fraction is always larger in grain-size than the non-magnetic. For example one separation had magnetic grains of .25 m.m. average diameter whereas the non-magnetic lay between .15 and .2 m.m. The amount of the residue was between .3 and 1.6 per cent. It is found that although there is considerable variation in the appearance of the sands there is none to be noted in their mineralogical composition. The amount of the components may vary somewhat, however. For example, among the more pebbly parts a very large percentage of garnet is found and may be due to its specific gravity. It will be sufficient to describe the minerals as generally applicable to the whole of the deposit. The minerals identified are the following:—

Cubic.	*Tetragonal.*	*Rhombohedral.*
Garnet.	Rutile.	Calcite.
Magnetite.	Zircon.	Ilmenite.
Pyrites.		Quartz.
		Tourmaline

Orthorhombic.	*Monoclinic.*	
Hypersthene.	Chlorite.	Hornblende.
	? Chloritoid.	Muscovite.
	Epidote.	Orthoclase.
	Zoisite.	Monazite.

Digitized by Google

Other Minerals.	*Triclinic.*
Serpentine.	Albite.
Leucoxene.	
Limonite.	

The light residue is composed almost wholly of quartz and a little felspar. The felspars are much clouded by decomposition; albite and orthoclase have been recognised.

Garnet. This is by far the commonest mineral present. Both colourless and pink varieties are found. Crystal form is never seen and the grains usually show a sub-conchoidal fracture. They vary very much in size. Occasionally there is anomalous double refraction confined to the coloured specimens.

Tourmaline. While not so common as garnet, tourmaline forms a large proportion of the residue. Fine prismatic sections are most numerous, but occasionally much-rounded specimens are present. Almost without exception the colour is brown pleochroic to almost black; only two blue specimens have been seen.

Muscovite is almost as plentiful as garnet. The flakes always show a remarkable degree of rounding. They give high order grey under crossed nicols and yield a perfect biaxial figure which is negative. Frequently large flakes, slightly green in colour, are observed and these have invariably a large number of inclusions the majority of which appear to be biotite.

Zircon. This also is a common mineral and both colourless and purple varieties are found. Good prisms are seen capped by pyramids and also much-rounded grains. At the suggestion of Dr. Mackie attention was paid to fractured grains; these were occasionally found to show secondary outgrowths of pyramids.

Rutile. The foxy red variety of this mineral is fairly common. The grains are always much rounded and small in size.

Chlorite. This is a common mineral occurring in rounded flakes of an emerald green colour. In almost every case it appears to be isotropic. It often shows decomposition to a rusty brown colour. The identification has not been made perfectly definite but it is very probable that the mineral belongs to the chlorite group.

Augite. Large irregular grains of augite are present. They never show either form or cleavage and only in certain sections do they show pleochroism (green to brownish-green). The polarisation colour is green and colour rings are always seen at the edges due to thickness. The figure is usually a partial

Digitized by Google

biaxial one, one eye lying at the edge of the field. One good figure was obtained almost complete, and was negative. Probably derived from basaltic rocks.

Monazite. Rare. Pleochroic from yellowish-pink to golden-yellow. In one case it gave a single eye of a biaxial figure, central in the field with strong dispersion of the brush. Sign positive. Extinction angle small.

Epidote. Only a few ragged grains present. Pleochroism good; colourless or very pale green to yellow-green. Biaxial negative figure.

Zoisite. A mineral very similar to the above in behaviour is present. As it gave, however, a positive sign it is believed to be zoisite.

Hypersthene. One specimen. Pleochroism green to pink. Straight extinction and positive biaxial figure.

Magnetite. This mineral is not uncommon in very small particles which never show any form.

Ilmenite is present in small amount. The grains are always much rounded and occasionally show alteration to a white coating of *leucoxene.*

Serpentine has been identified only by its aggregate polarisation.

Calcite occurs in rare grains.

? *Chloritoid.* This identification has not been confirmed yet, but a mineral which agrees with certain published descriptions of chloritoid was present.[1] In form the mineral was flakey. Refractive index 1.714. Pleochroic from dirty green to smoky blue. Polarisation colour a greenish blue. Sign positive.

This association of minerals is not a particularly rich one. It can be seen that they are all derived from acid and basic igneous rocks and from metamorphic rocks. It appears to the writer that the absence of such metamorphic minerals as kyanite and sillimanite, and of a granitic mineral like apatite, is remarkable. The absence of apatite may be due to the fact that the deposit is a river alluvium, as the mineral is often absent in such cases. The water probably carried a quantity of organic acid which would be sufficient to dissolve the mineral. At the same time it is to be remembered that some calcite is still present. The absence of the metamorphic minerals mentioned above cannot be accounted for.

Mechanical analyses were carried out but these are retained for

[1] P. G. H. Boswell. Geol. Mag., 61, 1924, pp. 255-256.

Digitized by Google

use when the whole of the loose deposits of the Clyde basin have been studied.

Summary.

The deposit shows that considerable variation has taken place in the river's history, as shown by the brown and grey clays and the sand and gravel bands. The mineral association is not a very rich one, and is remarkable for the absence of certain minerals which one might expect on the edge of a great area of metamorphic rocks.

Digitized by Google

No. XI.—The Apatites in Sedimentary Rocks as Indicators of the amount of Atmospheric Carbonic Acid in the periods of deposit. By William Mackie, M.A., M.D., LL.D.

A study of the heavy minerals (*i.e.* above specific gravity 3) isolated from sedimentary as well as metamorphic rocks shows that throughout a whole formation belonging to a particular period, the mineral apatite may be conspicuous by its absence while in another formation belonging to a different period the mineral may occur in abundance in every member of it. Occasionally one does come across a series of rocks belonging to a particular period in which the amount of apatite varies from division to division. Thus the Upper Old Red sandstone rocks of the Elgin area have been arranged in four divisions. In three of these apatite is present in varying amount, being very abundant in two divisions, in fair quantity in another and except for one thin bed—about a foot in thickness—wholly absent from the fourth. The mere question of presence or absence of apatite may therefore be in itself of great service for the purpose of correlation of rocks. Thus the Torridon Sandstone in great part contains only a minimum of apatite and in many specimens it is not to be found at all. The Moine schists, once themselves sandstone, at least sediments, on the other hand yield apatites in abundance. The inference naturally is that these metamorphic rocks could not have been manufactured out of rocks of the nature of our present Torridons. This aspect of the question—the question of the mere presence or absence of apatite—needs only to be mentioned to be recognised as of value from a stratigraphical point of view.

It may be contended and the contention may be true in some cases that variation in the quantity of detrital apatites in a formation may take place from point to point in consequence of the rocks yielding the debris—eventually transformed into sediments, themselves varying in their content of apatite. If there are no

Digitized by Google

apatites in the former there can, of course, be no apatites in the latter. But apatites may be abundant in the rock from which a given sediment was derived and yet contain none itself. Thus the Cambrian Quartzites of the N.W. of Scotland, undoubtedly derived in great part from the Archean gneiss which contains apatite in abundance, contain only the merest traces of apatites. The Moine schists as already indicated contain abundant apatite, whence derived we do not know, but it is quite evident that the series of rocks from which they were derived contained quite a large quantity of apatite. The case of variation of the different divisions of the U.O.R. Sandstone of the Elgin area already referred to might be attributed to variations in the source of the sediments in the various divisions, but I think that such minor differences in source of supply as are indicated, were quite inadequate in themselves to produce the observed results. Such marked differences in their content of apatite as obtained in the various divisions of the U.O.R. of Elgin suggest another cause.

It is well known that apatite is scarcely soluble in distilled water. In rain and river water and more particularly in ground water as well as in ground air the content of CO_2 is much increased and in contact with these, the solubility of apatite would be proportionally increased also.

Rain water may contain 40 times as much as exists in atmospheric air, while ground air may contain several hundred times as much; sea water is credited with a content of CO_2 40 times as great as rain or river water. It stands to reason if the content of atmospheric air is increased from any cause, these others would be proportionally increased also; if decreased, they would be decreased in like proportion. The contention therefore is that these marked variations in the amount of apatite in the various sedimentary formations have been due to variations—call them secular if you like but there need not have been anything very secular about them—in the amount of CO_2 in the atmosphere.

The Carboniferous period jumps to the mind as a period in which, as many geologists believe, there was a great abundance of CO_2 in the atmosphere as being a necessity to the maintenance of the excessive growth of vegetation then prevailing. As a result the proportion of apatite in the sediments then forming would be in large part dissolved. That such was the case we shall presently find.

Digitized by Google

1. The case of the presence in abundance of apatite throughout the sediments of a particular period is one that requires little or no qualification but may be accepted with more or less confidence as indicating a presumption that little or no CO_2 existed in the atmosphere of that particular period. It is the negative phase—that is where apatites are absent or comparatively scarce—that calls for investigation. Apatites may be absent from or scarce in 2 sedimentary formations from:

(*a*) The absence or scarcity of the mineral in the rocks yielding the sediments.

(*b*) Pre-depositional solution *i.e.* when the rock debris was in transit from its original source to its final resting place in the strata.

(*c*) Post-depositional solution *i.e.* solution after incorporation in the strata.

(*a*) If the origin of the sediment is known, a fair estimate of the amount of apatite it originally contained may generally be made; thus if it is known that a granite or granites yielded the original debris—and this can usually be determined—a fair proportion of apatite may be safely counted on as an integral part of it.

(*b*) Pre-depositional solution, that is, the disappearance of apatite in transit, really marks the period of operation of the solvent agencies of the period.

(*c*) Post-depositional solution on the other hand really constitutes the Gordian knot of the position and may be impossible of determination with anything like certainty. Thus the Rosebrae division of the U.O.R. sandstone of the Elgin area contains in contradistinction to the other divisions of the U.O.R., a mere trace of apatite and that only in one particular bed. It is known that certain substances, e.g. $CaCO_3$ have been washed out of this division, while other substances have been deposited in it since the first accumulation of the strata; but then again the division of Newton which adjoins the Rosebrae and has been subject to the same conditions contains apatite in abundance. What is the inference?

II. Again the agency or agencies under which the sediments accumulated may account for much. From the softness of the mineral apatite, it is natural to suppose that Æolian agencies would be inimical to its preservation and lead to scarcity or even the total elimination of apatite from the finished product. Thus

Digitized by Google

the Cuthieshillock sandstone of the Elgin area was accumulated under æolian conditions and not a particle of apatite has ever been found in it. Again deposition in fresh water as against deposition in sea water is calculated to show wide differences in results, sea water as already indicated having so much greater a content of CO_2. In this connection we may contrast the Cambrian quartzites with the M.O.R. sandstones of the North of Scotland.

III. It may be of interest in cases where there is a deficiency of apatite to determine whether the mineral has vanished by attrition or solution, and there is often evidence in the sediments themselves to decide. The mineral monazite is very frequently present in the sediments along with apatite. Now monazite is a mineral approximately of the same hardness as apatite; it is, of course, of much higher specific gravity, and consequently would more speedily vanish from sediments by attrition than would apatite. The latter mineral on the other hand is more soluble than monazite and would in consequence disappear by solution more easily than monazite. For the purpose of illustration of this point there is now given a tabular view of the results so far obtained from Scottish rocks. With this has also been incorporated the quantitative results in regard to their content of apatite of the different sedimentary rocks of Scotland.

The records of heavy minerals in the sedimentary rocks of both Scotland and England are so far very incomplete and as regards the presence or absence of apatite—to say nothing of the all but complete silence in these records as to quantities relative or absolute—in many cases this mineral has been altogether ignored by workers in this particular field. Determination of the heavy minerals present in some of the Carboniferous rocks of Scotland was made by T. O. Bosworth a number of years ago. From the absence of apatite and monazite from his list of minerals one would naturally infer that these minerals do not occur in the Carboniferous rocks of Scotland. But sure enough they do in quite appreciable though on the whole relatively small amount as regards apatite. Monazite on the other hand is more abundant than in any of the other sedimentary rocks of Scotland. Another feature of some of these Carboniferous residues is the presence of rhombs of dolomite; especially is this the case when the separating liquid has not been of sufficient density (3 or slightly over) to float off the residual dolomite. This is important because the dolomite may be mistaken for apatite. Its presence at least

Digitized by Google

materially complicates the process of diagnosis. Another observer who has worked on the heavy minerals of the English Trias is candid enough to admit that he has ignored apatite as being a mineral easily attacked by and disappearing under the influence of acid conditions; that to record its occurrence where it does occur, would be to give a false impression of variation where there really was none. Another temptation to ignore the presence of apatite is that it is in the main of very little use for the purpose of correlating strata or for tracing the origin of a particular sediment as it is of too uniform character to have any specific value in that respect. Exceptions, however, occur. Thus the large apatites separated from a rough calcareous sandstone by the technique about to be described were found to show inclusions of zircon and monazite which is a characteristic of the granite of Rubislaw, Aberdeen, within three or four miles of which granitic intrusion the sandstone was collected. To continue the account of the work done on the English sedimentaries we may note that Travis and Greenwood published as long ago as 1911 a research on the minerals of the Trias rocks of the Wirral peninsula in Cheshire and recorded the presence of apatite in specimens from three localities out of forty-nine tabulated. From this result one infers a limited crop of apatite in the Trias of the Wirral. In this respect it agrees with the Trias of Elgin. Professor Boswell of Liverpool, has worked for the last ten or a dozen years on the heavy minerals of the English sedimentaries, first on rocks of Eocene age when he found apatite in the Thanet sands, Reading Beds and the London Clay. One infers from his description that apatite is most abundant in the first group and is less and less plentiful in the other groups in the order of statement; from which we infer an increasing gradient in the amount of CO_2 in the atmosphere from the period of the Thanet Sands to the London Clay. At a later stage he investigated Jurassic and Cretaceous Rocks. He makes no mention of apatite as a constituent of the Greensand or Cretaceous rocks he examined, but in his list of general occurrences he credits the Greensand of Huldon with a minimum of apatite. With regard to rocks of the upper Lias, apatite occurs rather more plentifully in the samples from boreholes, which fact implies a caution as to the careful selection of sample specimens. The records for Oligocene and Pliocene beds appear to be negative.

I have attempted to put the results of the examination of the sedimentary rocks of Scotland so far as they have been up to the

Digitized by Google

present investigated on a roughly quantitative basis as regards their contents of apatite. This has been done by isolating the quotum of heavy minerals from the specimens examined, taking care that no process is adopted which will dissolve the contained apatites. This caution appears to be quite necessary for I find that the first thing to be done usually is to plunge the prepared specimen into dilute hydrochloric acid. If this is done one necessarily says goodbye to any chance of finding apatites. But suppose the specimen has its particles covered with hydrated iron oxides or that it contains calcite or dolomite as a cementing substance as often happens, what is then to be done? Proceed with the separation of the heavy minerals in the ordinary way, using a separating solution of at least specific gravity 3 for the final separation. This will get rid of any calcitic or dolomitic cement. Then having well washed the heavy residue and transferred it to a watch glass, the ferric oxide may be sufficiently removed from the grains to allow a perfect diagnosis to be made by rubbing the residue with the addition of a little water, between the end of the finger and the bottom of the watchglass. It is wonderful what a little friction will do in the way of clearing up, not only the apatites but the other minerals present as well. The separated ferric hydrate is finally washed away before mounting the specimen, which is as evenly spread in the mount as possible. One advantage of using a watch glass is that the product can be inspected under a low power of the microscope and any defect remedied accordingly. Of course many specimens require no preliminary treatment for either ferric hydrate or cementing substances. In the specimen as mounted the apatities are counted as so many per field of $\frac{1}{8}$ inch objective, much in the same way as the bacteriologist estimates the numbers of T.B. in a preparation. This is best done in the first instance under crossed nicols, the apatites then appearing as white or gray points or with central colours rising to yellow or even red in the larger grains. Any lying in the position of extinction will be revealed by moving the nicols through a few degrees either way. This serves to reveal the positions of the various apatites, when they may be finally rounded up in ordinary light, counting such particles as may be lying on the basal plane, which are then to be looked for and included in the number representing the total field Each determination as recorded is the average of 15 or more fields. Sometimes when the apatite particles are small or are very numerous,

Digitized by Google

it may be necessary to use a $\frac{1}{4}$ inch objective, the result being finally reduced to the $\frac{1}{2}$ inch standard. To this process of reduction is to be attributed some of the very high records obtained; the highest being of a concentration layer in the U.O.R. of Newton, which gave the phenomenal number of 120 per field. No great accuracy is claimed for the method but it is probably sufficient for the purpose of comparing specimen with specimen. A purely quantitative chemical estimate of the phosphoric acid present is theoretically the ideal method but that involves a preliminary separation of the last trace of silica an operation which takes up much time and requires very careful manipulation. The phosphoric acid might then be estimated either gravimetrically or colorimetrically.[1]

We are now in a position to summarise the quantitative results so far as they appear in Scottish rocks and we shall begin with present day conditions because these as in so many other things supply the key to the interpretation of the past.

As regards present day conditions we have the following:—

	per field.		per field.
(1) River Sands - -	1.6	(7) Other - - - -	0
(2) Culbin Sands - -	1.26	(8) Morainic - - -	0
(3) Sea sands - -	.42	(9) Highland gravels - -	1.3
(4) Boulder Clay, - -	1	(10) Sand, River Tay, Birnam	0
(5) Wind Blown Seasand Results from Norway	0	(11) Valley Moraine, Tay Valley, less than -	.2
(6) Stream Sand, - -	3.3	(12) Rocks in Tay Valley Drummond Hill. -	5.3-35

From a study of these we may derive some general principles bearing on the disappearance of apatites during the progress of rock-waste from the original rock masses to its final deposition in the sedimentary strata.

(1) From *river Sands* a considerable portion disappears by solution caused by the CO_2 content of river water; in (2) *Culbin Sands* which have mostly been for varying periods in sea water as

[1] Ferric hydrate may be cleared off by heating the separated dense residue in acid sulphate of potash just up to complete fusion of the salt or till it just ceases to give off bubbles of gas or aqueous vapour, then washing or boiling out the melt, when the various minerals will be found to be very bright and clear. If the heating be carried too far the apatites, particularly if they are of small size will also be dissolved; but if the heating is carefully carried out the method is of at least quantitative value for the presence of apatites. Some of the other minerals present may however be attacked by this process and with such changes the observer must be fully conversant.

Digitized by Google

well as river water, in addition to undergoing aeolian attrition on a land surface. (3) Sea sands remind us that sea water contains 30 to 40 times as much CO_2 as river water and its prolonged action is likely to render marine sediments free or almost free from apatites. Deposition therefore under marine conditions may be taken as indicating a deficiency of apatites in the sediments accumulating under these conditions. (4) I have a general impression that all glacial deposits I have examined have given unexpectedly low results, which are not easily explained. Low temperature should indicate a higher content of CO_2 dissolved in the water but then a low temperature should be expected to retard solution. The question arises whether it is the higher content of CO_2 or the retarded solution that is the more important factor Evidently the former.

(8) and (11) are other cases of low results under glacial or post-glacial conditions. The results from Norway have been taken because the rocks of the particular area from which the specimens were collected were uniformly granitic, the rock-waste from which presumably contained originally a more than average quantity of apatite. (6) The sand of a fairly large but short river gives a fairly high result. (7) Was a small stream but the sand was mixed with much decomposing vegetable matter, which, of course, is a fruitful source of CO_2. That along with the action of vegetable acids may be expected to have caused a negative result. (9) is probably a result from the same river (6) at an earlier stage of its history. (10) Is an unexpected result, sand of the river Tay at Birnam. It might be suggested that it was due to the absence of apatite in the rocks undergoing denudation in the Tay valley. Against this, however, may be put the figure for apatite in the rocks from the east end of Drummond Hill, 5.3 to 35 per field; against this too must be put the result from the Tay valley moraine only about half a mile from the place where the river sand was collected. The latter, it should be added also, contained a considerable amount of decomposing organic matter.

We shall now take the geological formations in the order of their age, or as nearly as may be, beginning with the Moine schists, which no doubt originally formed an extensive sedimentary formation. As the result of the metamorphism they have undergone the apatites and a number of the other originally clastic minerals have been re-crystallised, but we shall probably not be far out in our estimate if we take the apatites as now existing in

Digitized by Google

these rocks as practically equivalent in numbers to those originally existing in the originally unmetamorphosed sediments. The examination of seven specimens of Moine schists from as many different localities and taking an average of five fields for each specimen gave over all an average of 7.8 per field—quite a high result as compared with many more recent sedimentaries.

The Dalradians in typical examples gave an average of 10.2 per field. In contrast with these the Leny and Margie grits were found sterile in regard to the presence of apatite.

TABLE OF QUANTITATIVE RESULTS AND CONDITIONS OF MONAZITES AND APATITES PRESENT IN THE SEDIMENTS COMPARED.

Geological Formations.	Number of Apatites per Field.	Monazite as to Frequency, Angularity or Rounding.	Apatite as to Frequency, Angularity or Rounding.	General Inference as to Conditions.
River Sands, Findhorn, Lossie, etc.	1.6	Quite a number of particles, angular, subangular & rounded.	Relatively few, angular, showing traces of prism.	Disappearance, chiefly by solution, also by attrition.
Culbin Sands	1.26	Few, rounded.	About as many apatites, rounded.	Attrition & solution.
Sea Sand	.42	Fewer than in river sand, rounded.	Only an occasional grain rounded.	Further attrition and solution under Marine conditions.
Boulder Clay, Elgin	1	Occasional grain.	Very few, angular to rounded.	Chiefly solution.
Moine Schists	7.8	Frequently present, re-crystallised.	Present in variable quantity, often locally abundant.	Compare with Torridon Sandstones.
Ben Ledi grits	10.2	Has not been observed.	Abundant.	„
Leny and Margie Grits	0	„	Has not been observed.	„
Torridon Sandstones	.7	Very rare, only 3 particles observed out of over 40 residues.	Rare.	Attrition & solution
Cambrian quartzite	.2	Occasional monazite rounded	Very rare.	Attrition and "Marine conditions."
Silurian	.2	Not observed.	Very rare.	"Marine conditions'"
Lower Old Red Sandstone	.3	Not observed[1]	Rare, angular.	Attrition & solution.

Digitized by Google

Geological Formations.	Number of Apatites per Field.	Monazite as to Frequency, Angularity or Rounding.	Apatite as to Frequency Angularity or Rounding.	General Inference as to Conditions.
	Av'r'ge			
Middle Old Red Sandstone	8.4	Almost always present, often angular or idiomorphic.	Abundant.	Low atmospheric content of CO_2
Rhynie Oolitic	95		,,	
Tomintoul ,,	90		,,	
Donmouth ,,	5.6	Angular idiomorphic present, rounded.	,,	
Turriff ,,	0		None.	Solution.
	Av'r'ge			
Upper Old Red Sandstone	3.3	Present, rounded.		
Nairn Division	11.5	,,	Large quantity, rounded.	Low content of CO_2
Scart Craig ,,	2	,,	Fair quantity.	Aeolian conditions & solution.
Newton ,,	5	,,	Abundant.	Low content of CO_2
Rosebrae ,,	.2	,,	Absent except in one bed.	Aeolian attrition & solution.
Cardross (Clyde)	.2		Very rare.	,,
	Av'r'ge			
Carboniferous	.7	Abundant, angular, subangular & rounded.	Infrequent, may be idiomorphic or rounded.	Solution.
Upper C.	.7			
Bishobriggs	1.3			
Maryhill	1.46			
Dysart	0			
Millstone grit	0			
	Av'r'ge			
Permian	.46	Present, mostly rounded.	Rare, rounded.	Aeolian attrition & solution.
Arran (4)	0			
Benane Head	2.3			
Gordonia Beds	0	Present, Rounded.	Absent.	Aeolian attrition & solution.
(? Permian or Trias) Elgin				
	Av'r'ge			
(Trice) Trias (Elgin)	.6	Present, rounded.	Present, not abundant.	Solution.
Jurassic, Skye	.2	Present, fairly angular to rounded.	Infrequent, subangular.	Solution.

[1] NOTE (1) A single crystal has since been observed in a residue from Sandstones of Downtonian age, from Spittalhaugh, West Linton.

It should be noted that it has been observed in cases where the number of apatites has been reduced to a minimum they tend to show practically idiomorphic forms as if only the last comers into the sediments found a place in the deposits.

W.M. 23/11/25

Digitized by Google

We come now to the Torridon sandstone where a large number of determinations gave an average of .7 apatites per field. Comparing them with the Moines and Dalradians, by the latter meaning only the Ben Ledi grits, one sees at once that rocks of the composition of our present Torridons could not possibly be metamorphosed into either Moines or Dalradians. Passing next to the Leny and Margie grits we come to something that could very well have been derived from Torridons and it is very interesting to find that the suites of heavy minerals and the prevailing blackish colour of their residues are strikingly similar.

Next comes the Cambrian quartzites with a minimum of .2 apatites per field. Here we have undoubtedly the influence of marine conditions; but it should be added that quartzites generally representing as they probably often do the result of extreme attrition have uniformly been found to give low contents of apatite. Results in the Silurian have so far been found unsatisfactory. The finer sediments give practically no heavy residues and in the case of the rougher beds, e.g. " Haggis Rocks " the larger fragments are broken in the process of preparation of the specimens and probably give up apatites that were never directly exposed to the prevailing climatic conditions of the time. A very low content however is presumed in view of the marine conditions which obtained. When we come to the Old Red Sandstone, we are on surer ground. It has been found that results in L.O.R. and M.O.R. times differ widely. The L.O.R. has a very low content of apatite (.3) suggestive of the possibility of marine conditions of deposit, the M.O.R. a very high (8.4) on the average but in places reaching as high as 90 per field. There is also much difference between the two sets of heavy residues. Monazite has not been discovered in any L.O.R.[1] residues but it is all but invariably present in residues of the M.O.R. The sediment themselves also differ. In L.O.R. times the detritus was derived in a broadway from a higher zone of the Crust, from schists and schistose rocks while in M.O.R. times deeper zones, embracing such rocks as granites yielded their waste to the sediments of the time. The prevalence of volcanic rocks undergoing denudation in the L.O.R. period may partly account for differences in the sediments while the intensive and continued volcanic action in the period by giving a high carbonic acid content to the atmosphere

[1] See previous note.

Digitized by Google

may have helped to cause the low content of apatite in the sediments of the time. A singular feature amidst the profusion of apatite that characterises M. O.R. sediments generally is the total absence of the mineral in one particular outlier in the heart of Aberdeenshire, near Turriff. Though repeatedly looked for, not a single particle has so far been seen and no reason can be assigned for this peculiarity. It may be noted, however, that these sandstones are of the darkest red colour evidently indicating intense oxidation during their period of deposition. But then an abundance of hydrated peroxides of iron has elsewhere been found to be an interstratal preservative of apatites. During O.R. times things varied very much from first to last. At the beginning as shown by the results obtained at Kingsteps the high content of apatite characterising the M.O.R. rocks seems to have been maintained if indeed it was not actually exceeded for some time, getting smaller, however, as time went on with corresponding results at Scaar Craig (2) and Newton (5) in the Elgin area down to a minimum at the close of the period as shown by results from Rosebrae, Elgin, and Cardross on the Clyde (.2). This may be taken as in all probability anticipatory to the coming on of the Carboniferous in which a low content of apatite also prevails. The high content of CO_2 indicated for that period may have had several causes. The abundance of plant life in the greater part of the period is a suggestive correlative, but the high content of CO_2 indicated may just as well have been due to the volcanic manifestations of the time. In Permian times, the sediments give rather discrepant results at different localities but on the average they indicate a low content of apatite. Four results from different localities in Arran gave absolutely negative results, while one from Benane Head gave 2.3 per field. The Gordonia Beds of Elgin containing the remains of antique reptiles and of an age considered to be more likely Permian than Trias gave an absolutely negative result. The true Trias beds of the Elgin area gave a comparatively low figure and finally the only further result from Scotland, a Jurassic sandstone from Skye gave a minimum of .2 per field or less.

With this somewhat unsatisfactory result for the Jurassic sediments of Skye, we take farewell of Scottish rocks.

As has already been indicated, though much work bearing on the presence of apatites in the English sedimentaries has been done, as yet nothing definitely quantitative is available. Dis-

Digitized by Google

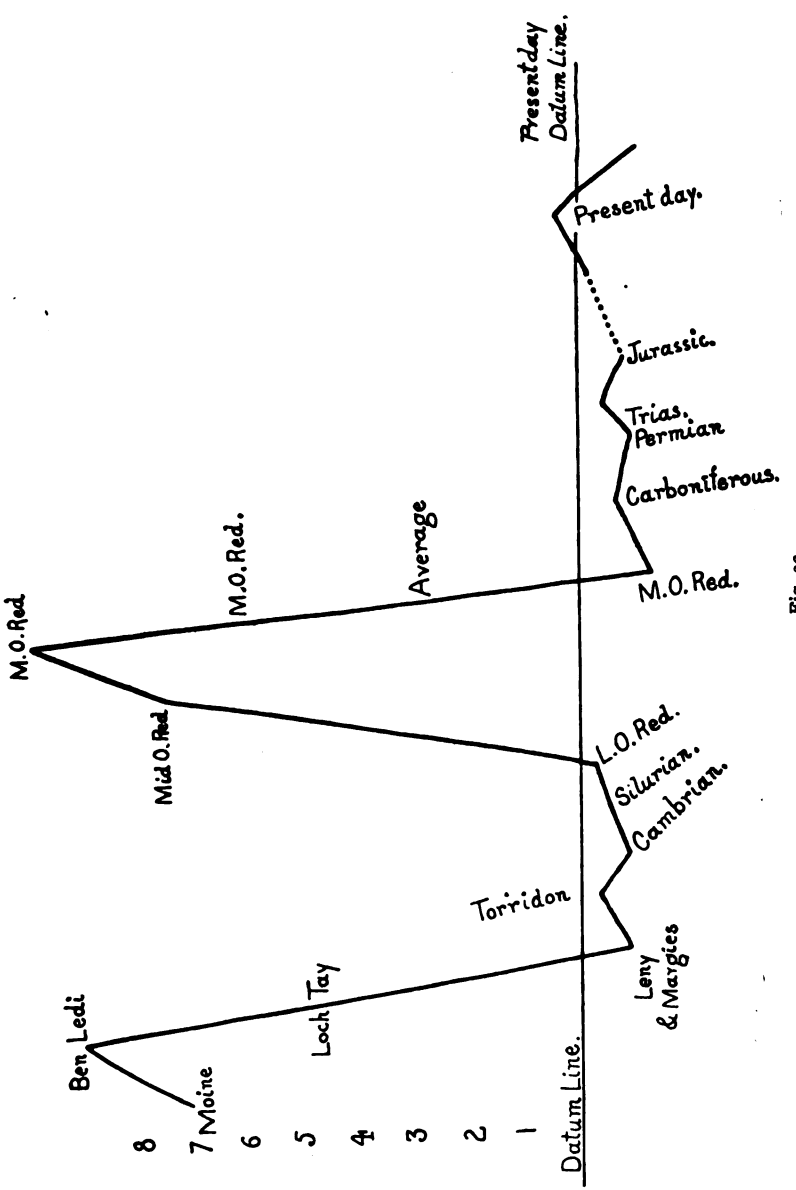


Fig. 32.

Digitized by Google

counting these for the present we are now in a position to summarise our results from Scottish rocks in the form of a graph, indicating the supposed quantities of apatite as ordinates and the geological periods as abscissa. These periods particularly in the earlier stages may not be in their exact order of sequence in time but they are probably as nearly correct as may be for all practical purposes. The quantities of CO_2 in the atmosphere being supposed to be in the inverse ratio of the proportion of apatite present, this graph to be read in terms of carbonic acid must naturally be inverted or one must stand on one's head as it were to see it as carbonic acid.

The opinion has generally been held by geologists that the amount of CO_2 in the atmosphere has varied from period to period throughout geological time and it has even been stated to have been greater in earlier than in later times. The Carboniferous period, I suppose largely on theoretical grounds has been instanced as a period when there was great excess of carbonic acid in the atmosphere and in this particular instance our results appear to confirm the view.

On the contrary, as regards a higher general content in early times our graph indicates—if it indicates anything at all—that the amount of CO_2 in the atmosphere existed at first in very minute quantity and increased later, coming finally at least so far as our results go to a fair and rather larger quantity later. The Carboniferous is one of the high early periods but it is not higher than in L.O.R. or Torridon times. Looking at our results broadly one may conclude that the amount of CO_2 in the atmosphere was to all appearance often less—infinitely less—than at present and perhaps hardly ever very much greater than it is now—probably never much more than twice as great. It may be asked what would be the effect if the present quantity of Carbonic acid in the atmosphere were doubled. I think from what we have seen as to what the present contents (3 in 10,000 parts) is capable of doing, it might reasonably be considered that such an atmosphere would be capable of sterilising all sedimentary deposits in course of formation, in regard to their content of apatite.

Another result according to Arrhenius, Tyndal and other physicists would be a decided rise in the average temperature of the globe. If we take all the sedimentary formations on our list with apatite determinations under, say—1 per field, that is to say

Digitized by Google

periods with a fairly high content of atmosphere CO_2, we have Torridon, Cambrian, Silurian, L.O.R. Sandstone, Carboniferous, Permian, Trias, Jurassic, all of them according to current geological opinion periods in which the temperatures were higher than at present. This would bear out the conclusion of Arrhenius, Tyndal and other physicists that a high content of CO_2 in the atmosphere is the cause of a high temperature. The first of these philosophers calculated that an atmospheric content of CO_2, two and a half times the present would raise the average temperature by 8 or 9 degrees. Be that as it may, the coincidence is certainly interesting but we are not discussing the cause of high temperature or even the cause or causes of variations in the amount of carbonic acid in the atmosphere. We have only been trying to show that there have been variations in the atmospheric content of carbonic acid throughout geological times.

Digitized by Google

No IX.—On the Occurrence of two Boulders of Kentallenite in the Neighbourhood of Greenock. By Rev. J. D. McCulloch, F.R.S.E.

These two boulders occur six or seven miles apart, one at Port-Glasgow, the other on the shore at Gourock.

At the end of 1923, in a paper on "Some Local Minerals,"[1] read before Greenock Philosophical Society, I described the Port-Glasgow boulder as kentallenite.

Shortly after the paper was published a friend who questioned my determination sent a small piece of the boulder to the Geological Department of the British Museum for examination. It was returned to him marked 'Dolerite.' Feeling confident I had not made any mistake, I wrote to the Department on the matter, and I was requested to forward a fragment of the boulder for microscopic examination when its nature would be put beyond doubt. I obtained from my friend the specimen already named "Dolerite," and sent it on. In due course, I received a letter stating that I was justified in calling it kentallenite, and that it certainly resembled a specimen so named in the Geological Collection at South Kensington. It was explained, however, that, "the rock, although containing some orthoclose, is a basic one, and is more closely related to gabbro and dolerite than to granite." I shall have more to say about this boulder later.

Having thus established one occurrence of kentallenite in the neighbourhood, I began to examine the boulders I came across in my rambles over the hills and along the shore, from Greenock to a mile or so beyond the Cloch in the hope of finding other occurrences. I was unsuccessful in my search until September, 1925, when, while going along the shore at Gourock, an angular boulder was found, which I recognised as kentallenite. I sent a specimen to Professor Gregory, and requested him to name it for me. He assured me on his own authority, and on that of Dr. Tyrrell who

[1] *Papers of the Greenock Philosophical Society*, 1924, p. 7.

Digitized by Google

had made a section of it, that there was no doubt whatever about the rock being kentallenite.

I mentioned to Professor Gregory that I knew of only two such boulders around Greenock. This fact he thought, seemed to suggest "natural occurrence." But there was just the possibility of the boulders having been brought round, as ballast, by boat, and not by ice agency, as was presumably the case. All doubt on that point would therefore require to be removed.

I made enquiry with a view to finding out if the occurrence of the Gourock boulder was other than natural. I interviewed the Provost on the subject, who said that, so far as he knew, no stones as ballast were ever brought to the town. The only stones likely to have come as such were those used in making the Esplanade and sea wall; and as it happened, all these without exception were taken from the shore, either as they were, or after being broken up.

On examining later some parts of the sea wall which have given way, I found many stones as the Provost described them, in their original condition—rounded and waterworn, or angular, with fresh surfaces, the latter being pieces of once larger boulders. I have no doubt whatever that the boulder I am now speaking of is one such piece. The surfaces are remarkably fresh, and little difficulty is experienced in making out the several constituents of the rock.

The boulder is on the shore opposite George Place, at high tide mark, and at a foot or so from the sea wall. At times it is completely covered by seaweed brought in by the tide; at other times exposed to view.

The following are its dimensions:—

Length: 24 inches; Breadth: 18 inches; Height: 14 inches. Taking the specific gravity of the rock at 2·71, its weight may be estimated at 5¼ cwts.

The Port-Glasgow boulder is situated at least half a mile inland at a height of 300 feet above sea level. It stands on the public road in front of Hamilton House, south-east of the town, and nearly a mile from it.

This boulder is well known in the neighbourhood both on account of its great size and its isolation from the surrounding rocks which are of volcanic origin, and of Calciferous Sandstone age. By the uninitiated it is supposed to be of the same character as the surrounding rocks, but for some unknown reason has become separated from them. More, however, on account of its legendary associations, than its geological structure and origin has it gained notoriety. It is familiarly spoken of as "The Bogle Stane."

Digitized by Google

Tradition says it originally stood on the farm of "Laigh Auchinleck," when it was much larger than at present, and famed for a bogle, or impish spirit wont to frequent it. But at the instigation of a local cleric who had no regard for such superstitions, and wished to abolish them, the stone was blown up by gunpowder. Some of the pieces were built into the neighbouring dykes, and others converted into curling stones. Later, an effort was made to preserve the stone by reuniting the broken pieces. The story of its restoration written by a local poet was inscribed upon it and added greatly to its interest until effaced by the weather.

Another story is to the effect that the Bogle Stane has always occupied its present site, but originally jutted out on to the public roadway. Being thus dangerous to pedestrians and vehicles, particularly on dark nights, the authorities within comparatively recent years, had the part of the stone nearest the roadway removed. But not without disastrous effects; as the whole stone was badly shattered. Whichever story is the correct one, there is no doubt about the condition of the stone to-day. It is broken up into many large pieces; these have all been brought together, and as far as possible made to fit into one another in an attempt to restore the stone to its original shape. As frequent search to discover missing pieces of it has so far proved unavailing, one is disposed to think that probably all the Bogle Stane is there.

In a History of the district, written some fifty years ago, the author describes the Bogle Stane as "A large quadrangular block of whin, eight or nine feet high, standing in a field, close by the wayside, with a grassy top, and able to accommodate half a score of persons." It has evidently undergone no change in the interval, for it still has its grassy covering, and so far as can be estimated, may still quite easily provide standing room for as many persons as the Historian names.

The following are its dimensions taken on a recent visit:—

Length: 13 ft.; Height: 8 ft.; Breadth: 8 ft. 6 ins.

Estimated weight: 66 tons, 17 cwts.

Its great weight and elevation above sea level seem to dispose of the idea that it was brought as ballast by boat to the nearest port and later transported by human agency to its present situation. It appears to be one of the many erratics found in the neighbourhood of Greenock.

Although the most careful examination has been made at different times, no ice grooves or scratches could be discovered.

Digitized by Google

How were these boulders brought to their present situations? While boulders of other kinds of rock, brought to the neighbourhood by ice agency, can be counted by the score, if not by the hundred, boulders of kentallenite appear to be exceedingly rare.

Were they carried from the parent rock in Kentallen by glaciers and left where we now find them? Or were they carried by drifting ice? Personally, I incline to the latter view.

Digitized by Google

No. X.—THE DOLERITE BOSS OF SITHAN-T-SLUAIN. By JAMES HOLMES, B.Sc., GEOGRAPHY DEPARTMENT, THE UNIVERSITY, GLASGOW.

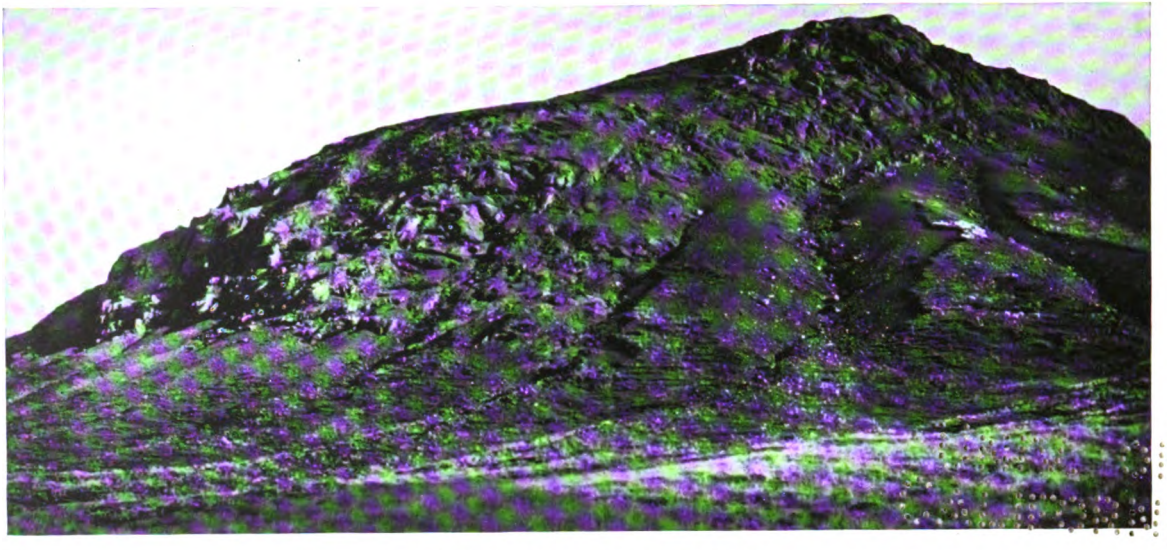
CONTENTS.

INTRODUCTION 425
GENERAL DESCRIPTION .. ..
PETROGRAPHY .. ..
1. The Contact Rocks.
2. The Dolerite Fringe.
3. The Pegmatite Rocks.
4. The Main Mass—Allivalite.
CONCLUSIONS .. ..
DESCRIPTION OF PLATES .. ..
REFERENCES .. ..

INTRODUCTION,

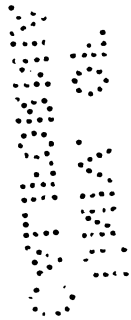
SITHAN-T-SLUAIN is the name given to a conspicuous eminence (500 ft.) above the general plateau level (1000 ft.) of that portion of the Highlands south of Loch Fyne, Argyllshire, Scotland. The name itself, associated as it is with many local traditions, proved an interesting little holiday study. "Sithan" translated from the Gaelic means "Fairy Hill" or "Green Hill," while an annotated copy of Scott's "The Lady of the Lake" gives "Sithan" as "Men of Peace" whence it was thought that the hill obtained its name because certain monks used it as a place of refuge when their monasteries were raided. It is more probable, however, that this hill was a landmark indicating the direction in which the Men of Peace resided. Some Gaelic dictionaries give "Sith" as meaning peace, spiritual, fairies, or green hill, while "Sluain" or "Sluaigh" means people. Tradition has it that this hill was so named out of regard for those gentle folk about whom all manner of strange tales are to be found in Celtic Folklore. Modern inability to appreciate the Gaelic sentiment has had the

Digitized by Google



Summit of Sithan-t-Sluain from the North.
Ring Dyke and Contact Aureole well seen to left. E-W 200 yards approx.

Digitized by Google



Digitized by Google

effect of stigmatising this 1500 ft. hill as the Fairy Knowe, a name I find convenient for use in this paper.

General Description.

The Fairy Knowe (Sithan-t-Sluain) is situated on the south side of Loch Fyne about two miles east of Newton Bay, directly south of the croft known as Stuckreach. The summit (1428 ft.) of the hill (plate II) may be seen from almost any point in Upper Loch Fyne on account of the comparatively continuous steep slope to the loch side. It is easily recognisable as it is the highest of three summits on the ridge and instead of being grass covered, is black and ashy-looking with the accumulated fine scree of the rapidly disintegrating doleritic rock core. The Fairy Knowe is a dolerite boss (Clough, 1905, p. 120) with a comparatively flat top and almost vertical walls intruded into garnet mica schist and is therefore of later date than the schists. The uncrushed condition and the composition of the Fairy Knowe give it characteristics unique among hills in the district. The general shape of the visible portion of the boss is elliptical, extending some 300 yds. N N.W. to S.S.E., the shorter axis being about 100 yds. The summit slopes gently towards the south to a peat bog containing many beech trunks and therefore of the period of final glaciation. To the north the slope is precipitous, forming two shelves, then tapering away to a loose scree. The main mass (Fig. 33 L) of the

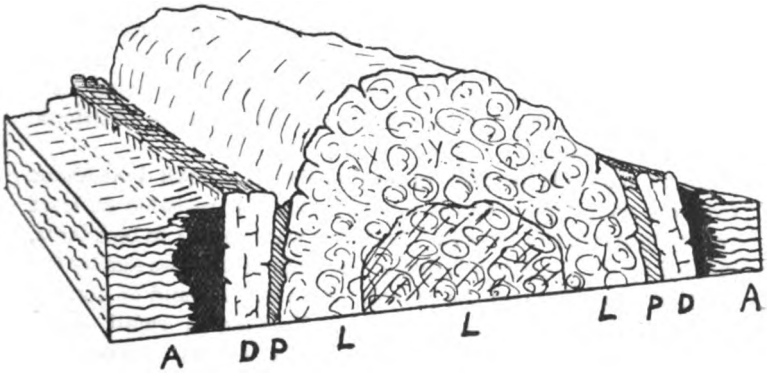


Fig. 33.—Diagram across Fairy Knowe illustrating rock types and structure of 'ring' dyke.

Digitized by Google

rock shows very large spheroidal weathering, the harder bands forming natural arches while huge egg-like masses protrude from the surface especially on the south side. A more detailed survey shows that this main mass gives place outwards to a coarse and badly weathered pegmatite rock often accompanied by a finer grained ophitic dolerite. The distribution of the ophitic dolerite is somewhat irregular but can usually be found at the edge of a joint plane in the main mass. The width of the pegmatite is 3 ft. and could be traced practically round the boss (Fig. 1, P.). Proceeding outwards there is a dyke-like mass of much finer grained, roughly jointed dolerite 30 ft. in width, which extends practically round the boss (Fig. 1, D.). On the inner margin of these rude columns small stringers of pegmatite may be obtained adhering to the dyke-like dolerite, not penetrating it. The outer margin has a darker, more glassy, appearance in the hand specimen but tachylite was not found. An aureole (Fig. 1, A.) of contact rocks is specially well developed and can be examined at a number of points around the boss particularly on the eastern side. The loose scree obscures much of the inner margin. A narrow band, three inches wide in places, of minutely jointed, roughly granular, badly weathered, amethyst-tinted quartzite and zeolitic material flanks the dolerite. The quartzite is succeeded by a band (6 ins. wide) of blue glassy spinel-hornfels, not schistose in character (buchite). The remaining portion of the aureole is a schistose rock (hornfels) altered to such an extent that the mica has lost its usual lustre, the cleavage planes have consolidated and dull greenish blue bands of fine grained material have been interpolated between bands of clear quartz grains.

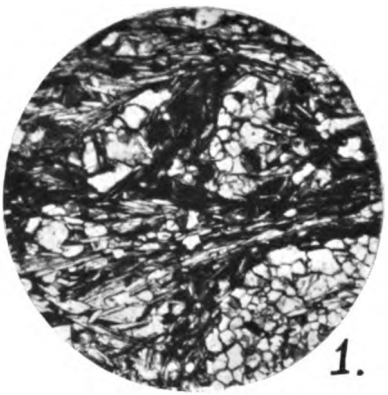
The schists outside the contact aureole being much softer, have weathered away, thus leaving this hardened band as an additional fringe to the boss.

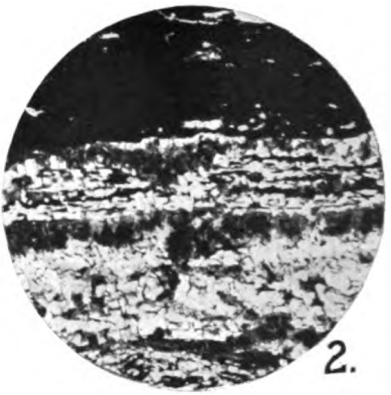
On the east side intruded into the schists is a small dyke about two feet wide which tapers outwards and is traceable at least twenty feet into the aureole. At first it was thought to be a fault, judging by the peculiar jointing of the mass of the boss and by the position of a terrace of the aureole above it. A band of buchite and zeolites flanks this apophyse. Further, a small badly weathered vein of limey zeolitic material occurs between the buchite and dolerite of the larger intrusion. This significant position of the metasomatic zone will be referred to later. On the flat summit there is a thin capping of soil and rock debris, which is

Digitized by Google

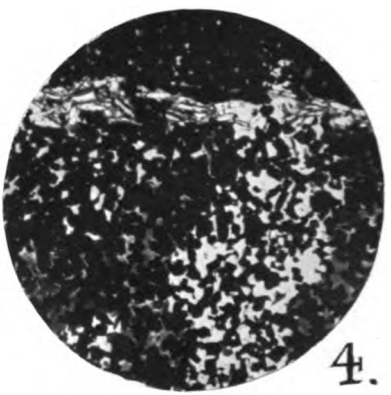
UNIV. OF
CALIFORNIA

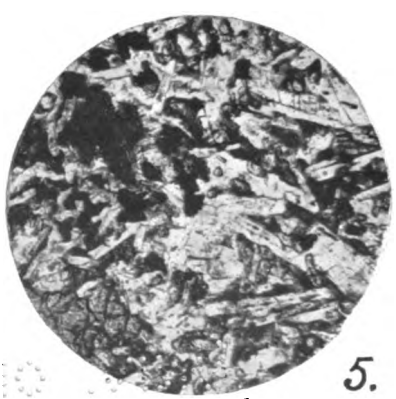
Digitized by Google

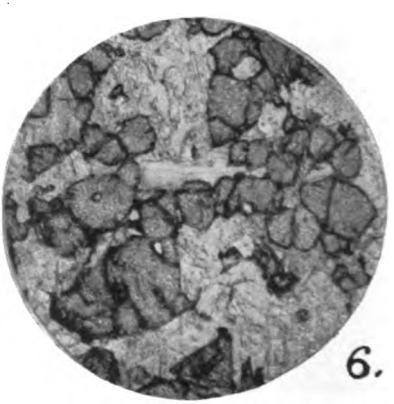

1.


2.

3.


4.


5.


6.

J. Holmes.

D. M. Fillshill, Micro.

Digitized by Google

composed of phyllites, slates, schists, quartzite, felsite and a few pieces of Garabal Hill granite, clearly not weathered *in situ*. Since the main mass of the boss is directly beneath this soil, it follows that the dyke and the pegmatite portions of the boss have been eroded away, which in view of the facts stated above can only have taken place during glacial or preglacial times. It may be possible therefore to deduce the amount of erosion which this region has undergone during glacial times, uplift, if any, being measured from the well developed raised beaches in the neighbourhood.

The further description of these rocks involves the awareness that considerable variation takes place within each member of the rock type, e.g. one slide shows more augite than another. From the numerous examples collected the essential characteristics were determined, hence it is sufficient merely to show in what way they differ from many similar rocks described in petrological literature especially in the memoirs for West Highland districts.

Petrography.

1. Contact Rocks.

Under this convenient heading three types will be described, including the unaltered country rock.

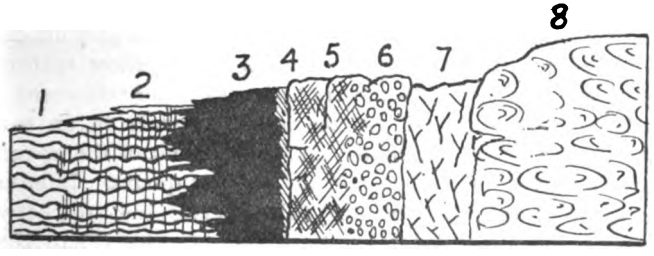


Fig. 34.—Diagram of relative distribution of rock types (not to scale). 1.—Schist. 2.—Hornfels. 3.—Buchite. 4.—Zeolite vein. 5.—Dolerite. 6.—Olivine-Dolerite. 7.—Pegmatite. 8.—Allivalite.

The country rock microscopically is a typical mica schist, much folded, with schistose planes between the quartz grains determined by lustrous white mica Fig. 2, 1.

Microscopically (Pl. 2, No. 1) the schistose structure is maintained. The slide shows essentially a granulitic admixture of

Digitized by Google

turbid and clear quartz grains lying between folia of fresh muscovite and biotite.

Considerable quantities of chlorite and ferric material have developed along the crush planes.

Felspars were not observed, while one or two pieces which may be garnet were present.

The second type illustrates the result of contact metamorphism, the extent of which was induration and penetrating solutions.

In hand specimen this rock differs from the schist in being much more compact. Fig. 2, 2.

The mica has lost its lustre and appears to be replaced by a band which weathers to a dull pale-blue surface. Other specimens have no resemblance to schist, and are more like a weathered basalt (hornfels).

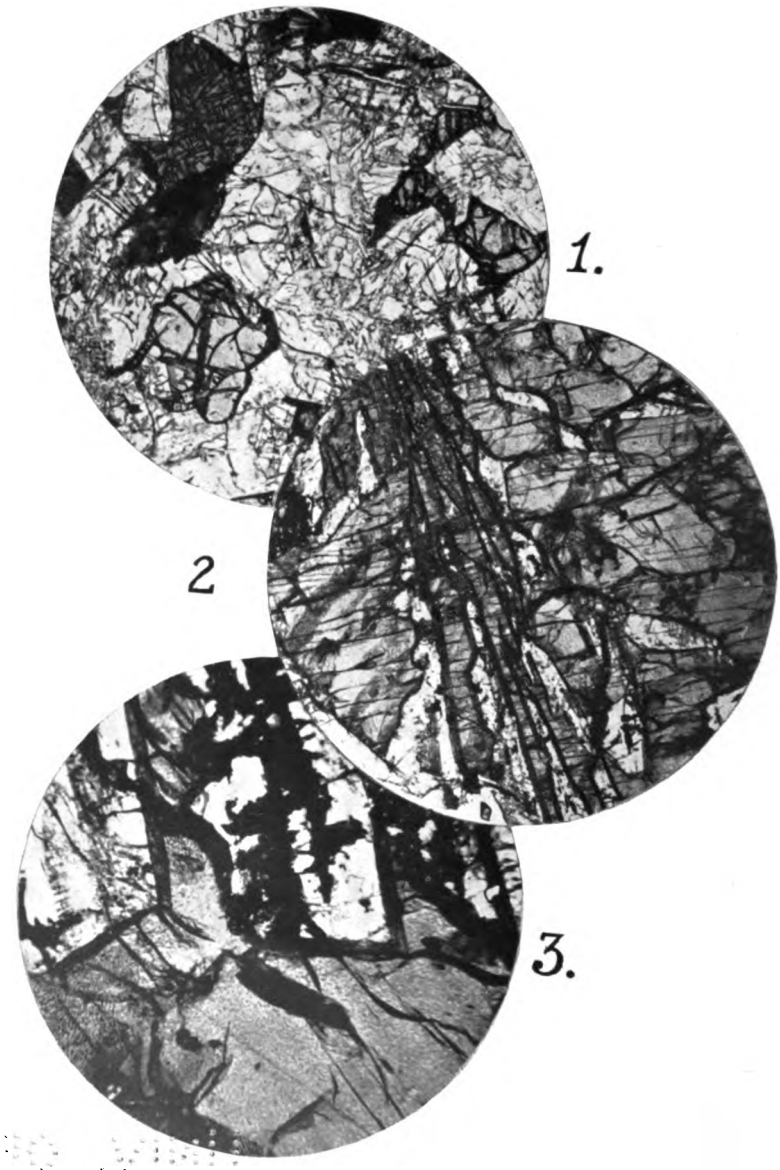
These have joint planes filled with black earthy material parallel to the previous schistosity. Characteristic rhomb-shaped three dimensional jointing is typical of the field relations.

In thin section (Pl. III, No. 2), the blue band can only be described as having the somewhat indefinite characteristics of a slate; narrow bands of limey material separating minute quartz grains combine to show strain slip and overfold structures. Occasionally a fresh-centred lath of biotite occurs, also clear lenticular areas, partly filled with minute rounded blue spinels, surrounded by ferric material. The quartz layers of the original schist are generally less altered, but developed between them and growing out of the altered mica are, firstly, areas of clear yellow spherulitic glass, and, built upon these at right angles to the schistosity, are radiating fringes of minute needle-like crystals in an earthy matrix. In optical continuity, and growing out of the margin of the fringe are well formed crystals of clear quartz. Interstitial yellow spherulitic glass of high R.I. occupies the area between this fringing portion and the unaltered quartz grains (Pl. III, No. 3). Occasionally a few green spinels are strung out along the biotite side, and in one case only there is a clear ruby coloured aggregate impinged on the interstitial glass. The third type in hand specimen is a compact, non-schistose, blue glassy rock showing dendritic markings on the weathered surface)Fig. 2, 3.) Microscopically (Pl. III, No. 4), the bulk of the rock is a greenish blue spinel (pleonaste or hercynite) embedded in a brown or clear structureless glass. The spinels, quite irregularly arranged, often show good rhomb-shaped edges; more often they are rounded,

Digitized by Google

UNIV. OF
CALIFORNIA

Digitized by Google



D. M. Filshill. Micro.

J. Holmes.

Digitized by Google

averaging one eighth mm. in size; corundum prisms with rounded borders occupy the remainder of the slide. These are arranged parallel to and continuous with their longer axis. This is the only suggestion of parallel arrangement and only a few of the specimens show this structure. The brown glass under high power shows at times fine hair-like crystals; one or two larger needles are sillimanite.

The high R.I. (1.56) of the glass suggests anorthite but no further evidence has been obtained. These rocks grade one into the other gradually. There is not an abrupt junction between unaltered schist and buchite while the buchite and dolerite are separated by a band of structureless zeolitic material. (Fig. 2, 4).

2. The Dolerite Fringe.

The rocks)Fig. 2, 5) represented here are fine grained olivine-dolerites. Microscopically (Pl. III, 5) the outer marginal rock is finer grained, darker, and more glassy in appearance than the inner side of this dyke-like fringing facies. Microscopically the essential difference from the dolerites described by Judd is the presence in the outer member of spinels and corundum similar to those in the buchite. They are usually found beside the olivine but often in the felspar. In the inner member (Fig. 2, 6) grain size is considerably increased, and augite decreases in quantity until the rock is practically an olivine-bytownite rock.

Occasionally radial and other zeolites are present but not abundant; these dolerites have therefore affinites with crinanites.

For further description see explanatory notes to the micrographs.

3. The Pegmatite and Ophitic Rocks.

The rock is an admixture of two types, an augite felspar pegmatite (parallel arrangement of some crystals 4 inches long, terminated by a minute graphic intergrowth of the same two minerals) surrounded by a well developed ophitic portion (Fig. 2, 7).

Microscopically (Pl. IV, No. 2) part of any one crystal fills the field.

A feature which is generally characteristic of pegmatites is present. Sometimes one mineral (labradorite) shows crystal boundaries; often it is the other (augite), but there are cases where no sharp boundaries occur, merely ragged edges of each mineral.

The reaction rim round the felspar (Pl. 3, No. 3) does not

Digitized by Google

extinguish either with the augite or plagioclase. Part of this rim consists of serpentine but elsewhere small laths of hornblende (?) are present. Considerable zeolitic areas are present. In them augite and felsar have been corroded; the newly formed matrix is of calcite; many needle shaped crystals are present. These areas are flanked by serpentine and magnetite. Augite seems capable of holding magnetite in its composition until the final stages of crystallisation.

4. The Main Mass—Allivalite.

The main mass of the boss is an even-grained, medium light-coloured rock often badly weathered (Fig. 2, 8).

In thin section (Pl. 3, No. 1) the felspar is bytownite with considerable penetrating stringers of less basic plagioclase. This is an indication that the felspars already formed were reacting with the magna to form a lower member of the continuous reaction series.

From numerous cracks in the plagioclase surrounding the olivine it is deduced that the felspar may have crystallised before the olivine. In addition numerous other cracks have formed indicating that some movement of the crystals took place before final consolidation. Some specimens, marginal to joint planes, contain augite which occurs as the final product of crystallisation.

Conclusions.

The first question which presents itself concerns the method of excavation of the region formerly schist but now occupied by consolidated igneous rock. The dyke is evidence that stoping did take place though no xenolithic material was obtained. Strain slip, faults and jointing in the schist are evidence that lateral thrust took place. These two phenomena—stoping and thrust—are corollary to the main episode—upthrust to form a dome, of which there is evidence in the altered strike of the schist and their accommodating dip.

What became of the excavated material? Some blocks would be detached and sink by gravity. The remainder would fuse on the outer margin to the condition of a solid solution and recrystallise in smaller bulk as buchite. Little, if any, would totally dissolve to alter the composition of the magma. Dolerites in the West Highlands intruded into different rocks, and liable to have their composition altered if solution took place are remarkably

Digitized by Google

uniform. An appeal may be made to other arguments. The temperature of intrusion of the magma could not have been very great as contemporaneously with the act of intrusion fairly rapid cooling took place (formation of the fine grained dolerite) accompanied by considerable liberation of heat to the wall rock. Vogt deduces that the probable temperature of intrusion of basic magmas is about 1300; and in this case certainly not much more (tridymite fringes in hornfels).

Further, if any appreciable quantity of the siliceous wall rock was even melted far less dissolved the heat used up would be sufficient to force the whole mass to crystallise. Bowen considers that melting of wall rock would cause the magma to form some crystals of the ingredient in which it was saturated, in this case olivine.

The portion of the Fairy Knowe at present exposed does not suggest that conditions favourable for solution did obtain in the ultimate position of the intrusion but took place just before intrusion. The magma, immediately previous to intrusion, must have been on the point of crystallisation (1922 (2), p. 622); first generation of olivines, much rounded. On the outer margin would be a viscous concentrate conditioned to form corundum and spinel which would be brought up with the intruded magma and injected into the foliation of the schist open to receive it as the result of upthrust; accompanying this injection some melting of mica and quartz took place.

Pratt (1899, p. 231) dealing with the origin of corundum, shows that "the separation of alumina as corundum from molten magmas (*basic*) is dependent upon the composition of the chemical compounds that are the basis of the magma. Upon the oxides that are dissolved with the alumina in the magma and upon the amount of the alumnia itself." The paper deals also with the special conditions necessary to form both corundum and spinel. The above statements agree with the physical facts enunciated by Bowen (1922 (1), pp. 550, 559) in regard to the inclusion of aluminous and siliceous material in basic magmas.

Morozewicz and Logorio dealing with solubility of alumina in a molten basic glass have shown that corundum and spinel were the first minerals to crystallise out when the glass began to cool. The hornfels shows such a basic glass while the buchite is definitely analogous.

The contact metamorphism therefore is partly thermal *in situ*

Digitized by Google

and partly deep seated. The origin of the spinel and corundum is mainly due to the power of the magma under considerable pressure to melt the wall rock and form these minerals on its outer margin as the first products of crystallisation. The excess alumina forms corundum, alumina and iron the spinel.

The formation of spinel caused a considerable loss of heat with resultant formation of olivine crystals. In this way the outer rim of the dolerite quickly reached a stage in differentiation to form augite, while the inner rim being nearer the source of heat had only reached the olivine stage. The increase of grain size and diminution of augite confirms this. The next stage was the progressive crystallisation of olivine and felspar (bytownite) forming allivalite, of which the main mass of the rock is composed.

The magma had now reached a stage when practically the whole upper space was occupied by olivine and felspar crystals with the consequent expulsion of magma from that area. The unexpelled residues reacted with the bytownite crystals to form in them less basic stringers; also some small augite crystals were formed. About this time a plane of weakness developed between the now jointed dolerite and the allivalite. It can be demonstrated that this is the most likely place for a second intrusion to take place, while cracks would also form across the dome shaped centre. The position of the pegmatite is thus explained. Many veins of pegmatite adhering to the joint planes of the main mass peter out inwards, but it is probable that the larger veins represent the migration of the residual magma outwards from the allivalite. The pegmatite represents a more acid differentiate in respect of both the augite and the felspar; the quantity of acid liquor perhaps augmented by previously dissolved schists as stated by Bowen. Harker attributes large size in crystals to the aequous and residual materials left in the magma, but it must also imply " thinness " of the magma so that the centres of crystallisation are widely spaced. The growth of these large pegmatites presents certain special conditions of crystallisation. The residual magma would be concentrated at the present position of the pegmatite. Containing fluxes it would not be very viscous, but it would probably contain some augite and felspar crystals.

The method of crystal growth must have been of such a kind that the augite was continually limiting the space relation of the felspar (Pl. 3, No. 2) and vice versa. The felspar would retain contact with the liquid magma at some point of its surface,

Digitized by Google

growth proceeding until stopped by the enclosing augite. The rate of growth of augite and felspar must have proceeded *pari passu*.

Crystal growth of the pegmatite type necessitates free circulation of ample quantities of fresh magma solution, and the initiation of few new centres of crystallisation. The most likely place for crystal growth to commence is outwards from some augite crystals on the side of the channel along which solutions are passing. The augite crystals, starting earlier than any newer crystals formed in the pegmatite, would continue to grow until the intervening space was occupied, the portion of magma enclosed between them forming a minute graphic intergrowth.

An analogous case could be made out for the felspars.

This conjestion of the channel renders the remaining solution immobile and resists further passage of solution. The ophitic portion could then be formed. The field relations—the adhering position of the pegmatite, its radial growth, the pyramidal form suggesting the gradually decreasing passage of sufficient magmatic solution, and the position of the ophitic portions—support the theoretical considerations. Finally total crystallisation set in with the formation of zeolitic stringers, especially between the buchite and dolerite and in the pegmatite. The metasomatic zone is therefore inside the contact zone.

Earlier in this paper the circular distribution of the dolerite was mentioned (Pl. II, Fig. 1). Whatever be the origin of ring dykes the dolerite here shows such a structure. It would not be out of place to indicate in what way this particular example of ring-dyke had its origin. The magma on its intrusion formed a fine grained margin increasing in grain size inwards. The power of the intrusion was then at its maximum and for a time upthrust balanced overliyng pressure. The whole subsequent process of crystallisation was one of decadent power. With loss of heat, loss of hydrostatic head took place. The main mass, now well on the stage for complete crystallisation, settled down (the dolerite was not able to do so because of early solidification in its marginal position. Between the dolerite and the main mass a fracture zone was initiated up which squelched unconsolidated magma and residual solutions, ultimately forming pegmatite. On the Clyde shore line and in the West of Scotland generally may be seen dykes showing similar structures indicated by veins of zeolites and coarser grained stringers. The arrangement of the major joints in

Digitized by Google

the respective areas, the tendency of the fine grained rock to form rude columns, the coarser grained allivalite in regular masses with the pegmatite in very irregular distribution (easily eroded—a feature also common to the schist) gives the resultant topographic form. The petrographical characters, analogous to those of other West Highland dolerites, show the age of the Fairy Knowe to be Tertiary.

Explanation of Plates.

(I am indebted to Mr. D. M. Filshill for the preparation of the accompanying photomicrographs).

Plate II.

Summit of Sithan-t-Sluain from the North. Ring Dyke and contact aureole are well seen on the left. E. to W. 200 yards approx.

Plate III.

No. 1. Unaltered schist. Folia of muscovite, biotite and quartz grains. This is a rather silicious part of the slide. × 60.

2. Hornfels. Micas altered to a fine grained indeterminate material, strain slip and fault structures (black). Bands of fresh quartz grains of various sizes. Radiating fringes growing out of altered mica. × 40.

3. Part of slide 2 enlarged.
Spherulitic glass, basaltic type, interstitial to quartz grains.
Radiating tridymite fringes (Lower R.I. than quartz) in earthy matrix. Clear quartz at terminations of fringe. × 100.

4. Buchite. Bulk of slide composed of green spinels in a brown or clear glassy matrix. Brown basic glass contains many sillimaniite needles. Band of corundum prisms partly redissolved occupies the remainder of the slide. × 40.

5. Olivine Dolerite (from outer margin). Rounded and transverse cracked olivine (often altered to chlorite and serpentine) surrounded by lath shaped felspars, mainly bytownite but also anorthite. Magnetite and minute rounded crystals of corundum and spinel are seen. Some of the triangular areas between felspars consist of brown augite, but much less in amount than olivine. Holocrystalline, microporphyritic. × 60.

6. Olivine-Dolerite (olivine and bytownite). Two generations of Olivine; subophitic plagioclase. Grain size of rock larger than that of No. 5. × 20.

Plate IV.

No. 1. Allivalite. Main mass of this portion of the slide consists of crushed intersecting felspar laths. Other portions show olivine predominant.
Bytownite, twinned and sometimes zoned, is the chief plagioclase.
Olivine rounded, centres fresh, margins and transverse cracks, sometimes altered to serpentine. Augite anhedral with good intersecting cleavages. (This was the only piece of augite in the slide, of which the micrograph is about an eighth part). × 20.

Digitized by Google

2. Pegmatite. Augite (small part of one crystal) shows cleavage lines continuous on opposite side of felspars, but not through them. Plagioclase (labradorite) is anhedral and often enclosed by dark green augite. Simultaneous crystallisation. Reaction rims filled with magnetite. Similar wave-like markings filled with magnetite inclusions. × 20.
3. Pegmatite. Labradorite filled with magnetite, and enclosed by augite with reaction rims on border. Plagioclase crystallised before beginning of solidification of augite. The magnetite here belongs to the final stage of crystallisation.
Note cracks in augite near boundary of felspar. × 50.

REFERENCES.

1885. Judd, J. W. On the Tertiary and Older Peridotites of Scotland *Q.J.G.S.*, 41, p. 354.
1897. Becker, G. F. Fractional Crystallisation of Rocks. *Amer. J. of Sc.*, 154 (4), p. 257.
1898 Van Hise, C. R. Metamorphism of Rocks and Rock Flowage. *Amer. J. of Sc.*, 156 (6), p. 75.
1898. Pratt, J.H. Origin of the Corundum associate with the Peridotites of North Carolina. *Amer. J. of Sc.*, 156 (6), p. 49.
1898. Pratt, J. H. Separation of Alumina from molten magmas and formation of Corundum. *Amer. J. of Sc..*, 158 (8), p. 227.
1905. Clough, C. T. The Geology of Mid-Argyll: *Mem. Geol. Surv. Scotland.*
1921. Barrell, J. Relation of Subjacent Igneous Invasion to Regional Metamorphism. *Amer. J. of Sc.*, 201 (1), pp. 1, 174, 255.
1922 (1) Bowen, N. L. Behaviour of Inclusions in Igneous Magmas.
,, Bowen, N. L. Reaction Principle in Petrogenesis. *Jour. of Geol.*, 30, pp. 177 and 513.
1922 (2) Vogt. J. H. L. The Physical Chemistry of the Crystallisation and Magmatic Differentiation of Igneous Rocks. *Jour. of Geol.*, 30, p. 611.
1923. *Ibid.* 31, pp. 203, 407.

Digitized by Google

No. XI.—The Reported Metamorphic Zone at Castlefern near Moniaive, Southern Uplands. By J. W. Gregory, D.Sc., F.R.S.

The contact metamorphism of the Ordovician rocks around the granites of Kirkcudbrightshire has long been well known and is distinct around each of these intrusions. South-west of Moniaive is recorded on the Geological Survey Map of Scotland, sheet 9 1874, a "zone of metamorphosed rocks" as extending on the northern side of the Castlefern Water from a little west of Castlefern Farm for four miles to below Glencrosh at the foot of Kirkcudbright Hill. The trend of this zone is approximately west-south-west to east-north-east. It is parallel to the general strike of the sedimentary rocks in the district, but is transverse to the general trend of the granitic intrusions. It is referred to in the Memoir of the Geological Survey in explanation of that sheet (No. 9, 1877, p. 22) as the schistose area from Craigneston Hill eastward to Moniaive. Craigneston Hill is about a mile east of Castlefern.

The granites of the western part of the Southern Uplands are arranged as a horse-shoe with the open end facing east-north-east. The northern arm includes the granites of Spango and Carsphairn; the western line consists of the granite of Loch Doon and the Merrick, and the massif from Cairnsmore of Fleet to Loch Ken; the southern arm extends from Auchencairn to Criffell.

This "metamorphosed zone" near Moniaive suggested the occurrence of granite at a slight depth below the surface. Such an intrusion might be a member of this Loch Doon-Criffell chain, the plan of which it would alter from a horse-shoe to an incomplete oval ring, the Spango outcrop being an independent intrusion along the Southern Boundary Fault of the Midland Valley. This "metamorphic zone" might on the other hand be due to an offshoot from the Loch Ken massif along the strike of the Ordovician rocks; if so the plan of the granites would be that of the letter E. The second explanation appeared to be favoured by the occurrence of two short lengths of dyke with the same trend along

Digitized by Google

the western continuation of the Castlefern valley, which is occupied by the Garpel Burn. Owing to the bearing of this "metamorphic zone" on the distribution of the Southern Upland granites I was glad of the opportunity, by the kindness of Mr. W. R. Gourlay, C.S.I., of a visit to Castlefern to examine these rocks.

This belt of rocks is traversed by the Shield Burn which rises on Glencrosh Hill and joins the Castlefern Water a little west of Castlefern Farm. The rocks are well exposed along the Shield Burn for about 500 yards in a plantation, and also in a conspicuous boss 100 yards north of the uppermost dyke. At the southern end of this section, at the entrance to the ravine, the rocks have been smashed by a fault, the grits crushed, and the slates altered by the development of chlorite. North of this fault the rocks appear in the field as a normal series of Southern Upland graywackes. Microscopic examination of a series of specimens supports that view. The rocks are mainly grits containing fragments of quartz and felspar, which are not cleaved or seriously altered. There is no development of granulitic structure around the margin of the quartz grains. The only evidence that I could see in the field which countenances the suggestion that the band is metamorphic is the crushed slate along the fault. That rock might be considered as dynamo-metamorphic as it is sheared and contains much authigenous chlorite; but the remaining rocks of the section are fair representatives of the indurated type of the whinstone or hard graywacke of the Southern Uplands. I only made the one traverse across the band as that appeared sufficient to indicate the nature of the "zone of metamorphosed rocks" along the Castlefern Valley. The band so marked on the map consists of Ordovician grits and slates with the normal strike, and with some of the rocks crushed by a fault; but it gives no indication of granite near the surface.

Digitized by Google

XII.—A Preliminary Study of the World Geometry of Structure Lines.

By A. Stevens, M.A., B.Sc., F.R.S.E. Lecturer in Geography, University of Glasgow.

Structural features on the surface of the earth have generally a linear arrangement. Within the limits of a fairly large scale map, that is to say, over such an area as that of the larger countries of Europe, they follow lines which on the map are sensibly straight. But sometimes within such limits, and nearly always over more extensive tracts, the lines are not straight. For example, the Hercynian trends in France are shown to be about east and west in the Armorican region, north east—south west in the Ardennes; while in the Central Plateau of France the trend lines form an elbow, where the Armorican direction bends round to that of the Variscan fragments. Again, the Alpine system is described as made up of arcuate members, diverging and converging on nodes. The marginal ranges of eastern Asia and the islands of the west Pacific are described as 'festoons.' These curving trends are related to resistent blocks, to which they are marginal, as the Alps and Carpathians are to the Hercynian Blocks, and the fold mountains of Asia Minor to the plateau of Anatolia; or they are related in the same way to the 'continental nuclei,' as the fold chains of eastern Asia to the Baikal Shield, or those of North America to the Laurentian Shield; and the relation is regarded as a causal one, which may be expected to throw light at least on the mechanics of the formation of the great terrestrial folds.

These linear arrangements do not admit of question; but before making assumptions as to their nature and relations, and especially before basing upon them conclusions of primary importance in the large questions of terrestrial architecture it would seem that a rigid examination of their true form is essential. Very many writers seem to be content with the statement that they are lines, and then proceed to make inferences in which are implicit certain special properties of lines which have never been established. Thus are laid the most crazy foundations for grandiose theories.

Digitized by Google

There can be no doubt that the ideas of most people, even of most geologists, on the subject of lines drawn on the earth are derived from the study of maps. Most of the great thinkers have been careful to work out their larger problems on globes, which give the only practicable representation of the earth which is not hopelessly misleading. Even they have been apt to work out details on maps, and they have been driven to present their results on maps, on which they have almost invariably been followed by their readers. Maps, and especially small scale maps showing large areas, are among the most misleading of things, and nothing is better calculated to suggest a false conclusion or to hide a false argument.

In particular, a straight line on a map has not as a rule any connection with any obvious line on the earth and, of course, neither on the earth nor on a globe is it possible to draw a straight line. Straight lines are important on the plane, but no very extensive area of the earth can properly be regarded as if it were a plane, or have its curvature ignored. The straight line is the shortest distance between two points on a plane. The shortest distance between two points on the earth is an arc of the great circle joining them: a great circle on the earth is the largest circle which can be drawn upon it, and its radius is equal to the radius of the earth, regarded as a sphere.

The meridians, or directions of north and south at every point on the earth, are great circles. Any line of sight also lies in a great circle. It follows that bearings or directions are the angles between one great circle, the meridian, and another, the line of sight to the point whose bearing is required. The directions of importance in geology are strikes and trends, and these lie in great circles. Hence if we wish to extend strike lines to see whether their trend is the same in more or less distant areas we must do so by means of great circles.

Since the meridians converge on the poles the direction of north and south is, in general, not the same at different points. A great circle, and therefore a trend, has not a constant bearing throughout its length, but is constantly changing its direction (Fig. 35). Similarly, a forward bearing and a backward bearing along the same great circle are not supplementary (in the geometrical sense). This difference, and the convergence of the meridians within a small space, amount to so little that on a topographic map both may be neglected. One must not be

Digitized by Google

misled thereby into the mistake that in considering a fairly extensive area like the British Isles or the continent of Europe similar assumptions may be made with impunity.

There can be described on the earth such a line that the bearing along it shall be constant. In the familiar Mercator map of the world the meridians are shown as parallel straight lines, and the distance between the parallels of latitude, instead of being more

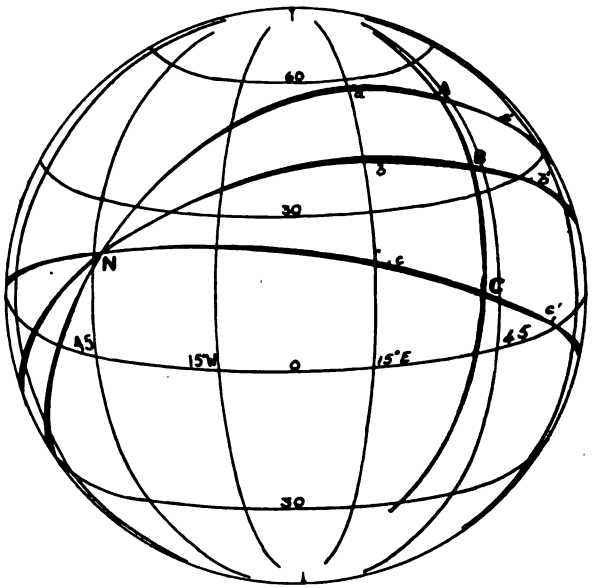


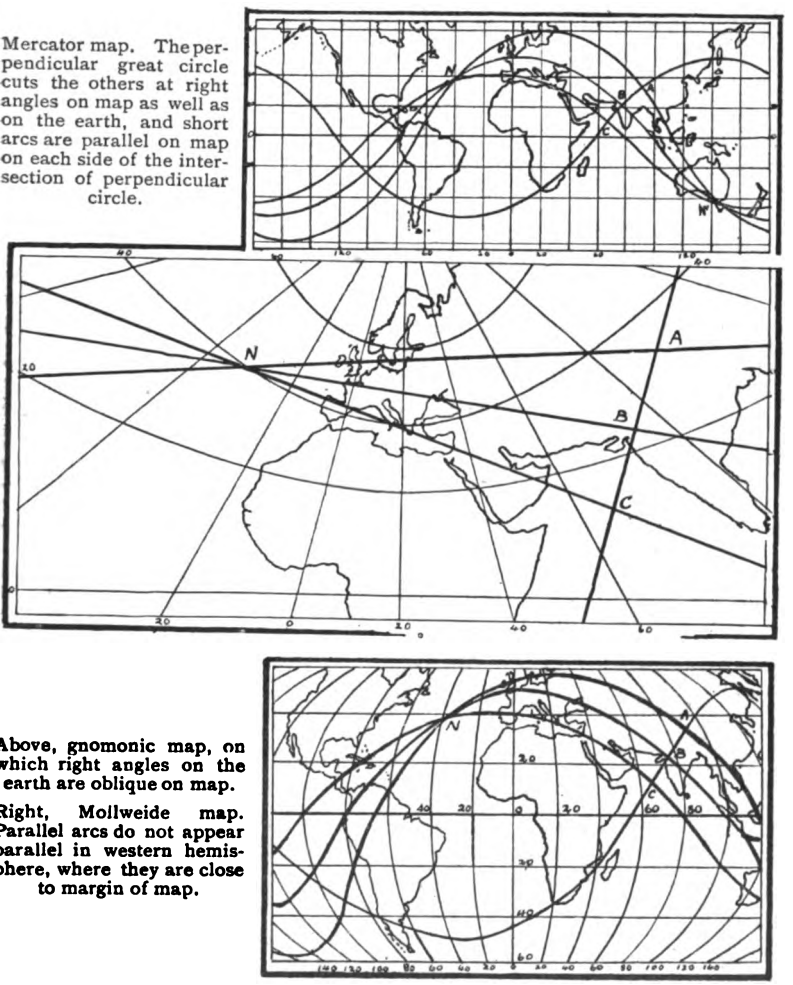
Fig. 35.—NA, NB, NC, are "parallel" great circles having a node at N. The great circle AC bisects the internodal arcs of these circles perpendicularly at A, B, C. The arcs *aa'*, *bb'*, *cc'*, are sensibly parallel.

or less uniform, is such that angles, and therefore bearings, are true on the map and can be measured from it. Any straight line will then cut all the meridians it crosses at a constant angle, and since the angles on the map are truly shown, it will be a line of constant bearing. Such a line is a rhumb line or loxodrome, very important in navigation, but having no simple relation to the form of the earth, like the great circle. Any great circle is a meridian if the pole happens to lie upon it (at present, or in a past geological epoch) and lag in the movement of the earth, due to

Digitized by Google

tidal friction or any other cause, would then tend to produce crumpling or rupture along it. The gnomonic (Fig. 36) map shows the great circles as straight lines, but it is not so useful in the study of trend lines as might be expected, for on a single sheet it can only

Mercator map. The perpendicular great circle cuts the others at right angles on map as well as on the earth, and short arcs are parallel on map on each side of the intersection of perpendicular circle.



Above, gnomonic map, on which right angles on the earth are oblique on map.

Right, Mollweide map. Parallel arcs do not appear parallel in western hemisphere, where they are close to margin of map.

Fig. 36.—Maps on various projections showing the same three great circles with nodes at N, N', and cut at right angles in A, B, C, by a third great circle. Cp. fig. 1.

Digitized by Google

be employed for something less than a hemisphere, sheets cannot be combined so as to make the features continuous from one to the other, and bearings on the map are not correct as they are on the Mercator. It is not easy therefore to use gnomonic maps for establishing the relationships between great circles, unless they happen to cross on the field of the map, when it can be seen what circles have a common crossing or node, a matter of importance, as we shall see, or unless they are parallel on the map, when it is a case of circles having a node on the circle parallel to them through, and distant 90° from, the centre of the map.

The most useful map on the whole for examining the broad world-relations of the great circles is the Mercator, because of its symmetry about the equator. The only difficulty is in the case of circles which pass through very high latitudes, partly on account of the great distortion of the shapes of the land masses there, partly because the Mercator map can only be constructed in practice to extend to about 83° of N. and S. latitude. Other maps which are capable of showing the whole world on a single sheet, although they have valuable properties in other connections, are so crowded in high latitudes as to be useless unless specially constructed to show these at the expense of other parts.

It may be pointed out before leaving the question of maps that small portions about the centres of different small scale maps look much alike; in other words, near the centre of such maps, and within the bounds of large scale maps of small areas, distortion is very small, and great circles in particular, so far as they cross the map, differ very little, often inappreciably, from straight lines. Towards the margins of small scale maps distortion rapidly becomes great and different maps show extreme differences.

In attempting something like a beginning of a rigid examination of trends on the surface of the earth, and in considering how far these trends may be identified with great circles, it is necessary to examine the relationships which may exist between great circles. For example, it has become a commonplace that trends are often parallel or sub-parallel over extensive, if somewhat narrow, areas. In what respect can parallelism exist between arcs of different great circles?

It is useful to define the great circle as the intersection of the sphere by a plane passing through its centre. Since the planes of all great circles pass through the centre of the sphere, two such planes must intersect along a diameter of the sphere, and any

Digitized by Google

pair of great circles will intersect in two points diametrically opposite to each other. Parallel straight lines in a plane are such that they never cross, and in such a sense great circles of a sphere can never be parallel. At a point on each of two great circles, half way between their points of intersection, the two great circles are parallel. Short arcs of the two circles on either side of these points will be *sensibly* parallel; that is, on a globe or on a map two neighbouring great circles will appear parallel for short distances. Take two great circles which are 10° (700 miles) apart half way between their nodes or points of intersection. At that point they are strictly parallel like straight lines in a plane, but for an indefinitely short distance only. But the extreme variation from strict parallelism 10° on either side of that point is less than 1° (Fig. 35). This is far too small an amount to be detected by mere inspection on ordinary maps, but not so small that it would fail to be revealed by careful examination or measurement. The parallelism of mountain ranges, for example, is seldom so complete as this, and individual ranges very rarely continue unbroken for anything like 20°, an eighteenth of the complete course of a great circle.

In this sense any two great circles may be said to be parallel. They will have a pair of nodes, and a stretch half way between them sensibly parallel. A third great circle will cut them half way between the nodes at right angles to both. A whole series of great circles may be drawn to pass through the same nodes, and all will be cut at right angles by the additional great circle. The parallel arcs of such a series of great circles will lie across the perpendicular great circle, and will form a series of parallel arcs such as constitute the great fold belts on the surface of the globe. A series of great circles having common nodes, and cut at right angles midway between these nodes by one perpendicular great circle, may therefore be described as a series of parallel circles in a special sense. It is only in such a sense that we have parallel directions on the earth, although the implication of the concept only becomes complicated when we come to deal with world- and other larger relations of parallel lines.

There is need, however, to consider another type of parallelism. The poles have not remained fixed throughout geological time. There is no more doubt about the fact of their migration than there is unanimity about the extent of it. Without opening up this question, we may note that the meridians are a set of parallel circles,

Digitized by Google

in our sense, and the nodes are the poles. If we could show that a system of fold mountains corresponded to a parallel series of great circles, then a further suggestion would arise. At some past time, perhaps at the epoch in which the strike of the folding became determined, it might be that the poles of rotation corresponded to the nodes of the system of great circles. There would then arise the question of determining the nature of tangential forces acting perpendicularly to the meridians which should be competent to produce the folding and which might be taken to have an obvious relation to the rotation of the earth. With the destruction of the supports of theories of secular cooling and consequent contraction of the earth it becomes more and more necessary to explore other possibilities in explaining earth-movements. In other departments of science it has proved unsatisfactory to leave out of account the form of the earth, the fact that it is in a state of motion, and under continual strains more or less normal to the meridians. But an important consequence of the earth's rotation is a tendency towards equatorward creep, and the deforming forces would act along the meridians, tending to produce features aligned at right angles to them, and along the parallels of latitude. In other words, we have here an orthogonal system, for the parallels of latitude are parallel with each other throughout their course, lying as they do in parallel planes.

The complete system, then, consists of a spindle of great circles, with a third great circle, which bisects all the circles of the spindle at right angles (it is the equator when the great circles are meridians), and a set of *small* circles lying in planes parallel to that of the third great circle.

In mountain systems as we know them the longitudinal direction is very marked. A transverse direction affecting more than valleys is not nearly so obvious; but it seems probable that in many cases transverse valleys follow fractures or lines of special weakness. 'Cross' features, in other directions than truly at right angles to the longitudinal are common enough, and seem to be due to interference with the characteristic direction by trends belonging to other systems. The less obvious transverse features may be very local facts directly associated with the dominant dislocation, or they may have a greater importance. In the latter case they may lie in the line of orthogonal great circles, or they may lie in small circles. Small circles are much more laborious to trace than great, and at this preliminary stage they have been left aside.

Digitized by Google

It is more than possible that some features on the earth, which exhibit very distinct curvature, can best be analysed as following small circles. To the present writer, after finding repeatedly that sharply curved features owe their outline apparently to the succession of one distinct direction by another, it seems unlikely, and that, in consequence, the main deforming influences on the earth has been normal to the meridians. The object of this paper being pure analysis we must confine ourselves to following out a few great circles; and the analysis of the great fold systems, with their parallelism and virgation, as lying along great circles in series converging at common nodes, seems to promise to be of interest.

A casual glance at the Cordillera of the Americas on a globe shows a strikingly close approximation to arrangement along a great circle, and even more remarkable is the continuation of apparently the same great circle in the north-eastern highlands of Asia. (Fig. 37). Beginning with the analysis of this line one is soon brought up by certain difficulties. Whereas the general trend of the Rockies is meridional, the strikes of the component rocks show many different directions, a north-easterly, a north-westerly, and perhaps an east and west predominating. There is something rather different from the 'general direction' of the Himalaya and the Appenines. In the latter case it seems to be due to ' side-stepping ' of strike ranges more or less along the general line of the mountains to which they are parallel. In the former something similar has been suggested.

In order to determine the great circles with such precision as is possible, it is best to work with a somewhat detailed geological map, and select a strike line which is distinct and continuous for a considerable distance. It is usually possible in fold mountain country to find such a strike line which is well marked over an extent of a hundred miles or more. Then it is necessary to discount the effect of elevation and topography in affecting the direction of the strike, and to choose several points on it. From the latitude and longitude of the extreme points the elements of the great circle passing through them are calculated,[1] and the next

[1] One is well within the accuracy of the data in treating the earth as a sphere. The latitude ϕ and the longitude l, measured from either of the points in which the great circle crosses the equator, are connected by the formula,

$$\tan \theta = \tan \phi \sin l,$$

where θ is the latitude of the most northerly (or southerly) point of the circle; that is, the angle between the plane of the great circle and that of the equator.

Digitized by Google

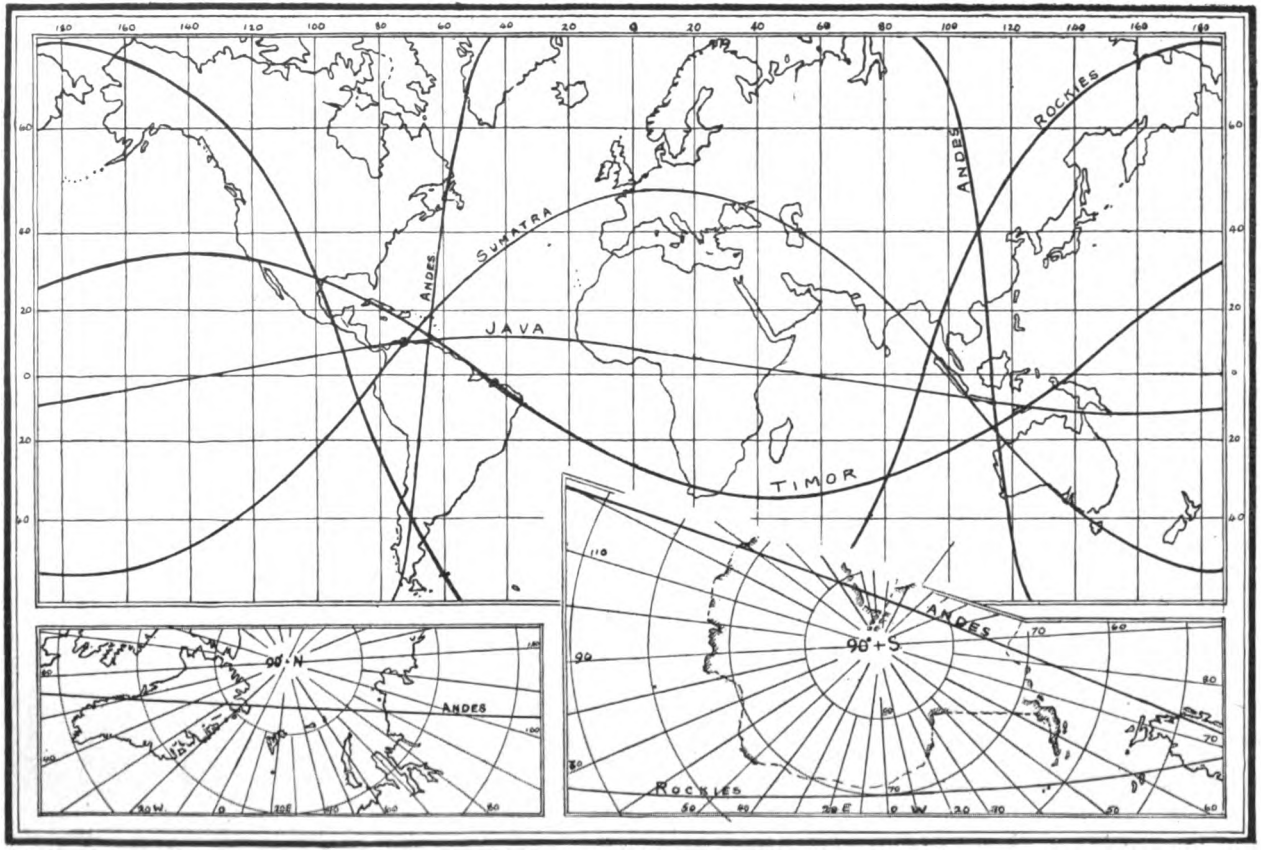


Fig. 37.—Trend lines of Rockies, Andes, Sumatra, Timor, Java. Below arctic and antarctic continuation of Andean and Rocky lines. (Mercator and stereographic projections).

Digitized by Google

step is to check these by the positions of intermediate points to make sure the line passes through them. It it does, it is a simple matter to calculate the latitude and longitude of any number of points on the great circle, and by means of these to plot the line on a map of the world. Examination of this plot will reveal where it is to be expected that the line will coincide with topographic features or strikes and trends of importance. Arcs of the circle can then be plotted on maps as detailed as required and on these the relations of the circles can be found with some precision. In this way many circles have been examined, and found to show remarkable coincidences at places far apart. It must suffice to trace a few here.

If the line of Sumatra be continued (Fig. 37), it passes north-westwards into India, slightly obliquely through the Nicobars, missing the Andamans on account of the ' bend ' of the Nicobar-Andaman ' arc,' and entering India on the 84th meridian at the mouth of the Languliya near the town of Chicacole. It passes inland parallel to the lower course of the Mahanadi and to the cliff on its right bank. The line crosses the Narbada near Narsinghpur, and beyond Aligarh it runs along the transverse portion (to the Aravallis) of the River Banas, a tributary of the Chambal. This is the first suggestion of parallelism with the lines of topography since leaving the Mahanadi cliffs, and from this point it shows none as it crosses the Sutlej by Bahawalpur and enters the mountains near Bazar Musa Khel. Further east, near Bara Khel in Afghanistan, the north-west line appears in the emphasis of transverse features, such as reaches in the rivers and truncation of ridges, but at Yarim Tapa on the Murghab above Merv the strike of the mountains of Khorasan asserts itself, and the Sumatra line borders these all the way to their end on the Caspian N. of Krasnovodsk at the mouth of the Gulf of Karabugas.

Approaching the west shore of the Caspian obliquely to the straight steep part between Baku and Petrovsk, the line enters Europe at the base of the Uch Peninsula, and sweeps away parallel to the ridges of the Caucasus, cuts off the Gulf of Taganrog from the Sea of Azov, and running up the valley of the upper Dneister forms a tangent to the great curve of the Carpathians south of Cracow From this point the concavity of the curve to the south is very little. It reaches its most northerly point in approximately 50° N., 10° E., close by the small town of Arnsteift in the valley of the Main. It cuts across the Bohemian Massif, and

Digitized by Google

unless one looks for trifling coincidences in river valleys, which are apt to be fortuitous, it is only after the line has crossed the French coast at St. Jouin a little south of Etretat that a further point emerges. The course goes on through Cotentin, to Pointe du Rozel on its west coast, passes south of the middle of Sark and skirts Guernsey to bend parallel to the north coast of Brittany and out into the Atlantic north of Ushant. In other words, the trend is that of the English Channel and important parts of the adjacent north coast of Europe. The track on the North Atlantic leads near the 4-fathom shoal west of Flores in the Azores and along a south-west sweep on the western margin of the Telegraphic Plateau.

In the West Indies it passes to the east of the Virgin Islands, and parallel to the edge of the continental shelf on this side of them, and enters South America in the peninsula of Paraguana, passing between the Cordillera de Merida and the Peninsula of Goajira and paralleling important sections of these and the Colombian Andes before reaching the equator in 80° W. longitude, west of the 19,000 foot peak of Cayambe.

Beyond the South American coast the direction of the axis of Sumatra passes into the deserted, and over wide spaces, unsounded, basin of the south-east Pacific, its course keeping well to the south-east of the Low Archipelago. Rounding the southern end of the sketchy 4,000 fathom line about the Kermadec Deep, it touches Antipodes Island, and runs parallel to, but well south of, the south coast of New Zealand, without paralleling any marked feature upon it. In the beds of the streams further north a parallelism of direction is suggested, as in the N.W.-S.E. reaches of the Clutha, the Taiere and the Waitiki.

Tasmania is entered at Long Point, and left again at Port Dalrymple, and the line joining these points is in the direction of stretches of the Macquarie and Tamar Rivers, the estuary of the latter, and arms of the fiord-like inlets of the south-west coast and parallel to the Greta and Lachuagan faults N. of Sydney. Beyond Port Dalrymple the trend is that of the Tasmanian coast between Devonport and Rocky Cape, and leads through Hunters Islands and by Bold Point, King Island. It runs inland parallel to the coast at Discovery Bay, passes close to Mt. Benson, crosses Kangaroo Island obliquely, runs along the south-west coast of the Flinders Peninsula and finally enters Australia at the rail depot at the Head of the Bight, to cross on a line which is all but straight

Digitized by Google

on ordinary maps, and pass out near Cape Thouin close to the 118th meridian. Here it is right in the line of the foliation of the rocks, parallel to folds near Pilbara to the west and Derby to the north-east, and parallelism is shown with foliation in the Petermann Mountains and in the mountains of the North-western corner of Western Australia. The trend appears also to be that of the Bangemall Anticline, which, however, takes a more southerly bend farther south. South of Sumatra in the East Indies the known contours of the ocean floor show no further features on this line.[2]

There is no doubt that such a chain of coincidences is remarkable, but it might be purely fortuitous. Examination of a great many other strike lines continued as great circles shows coincidences quite as striking, and reduces the possibility of purely accidental correspondence. There is a good deal of labour in working out the lines, and following them in detail is rather lengthy a process for a short paper. Nevertheless one or two more may be sketched. One very remarkable one is suggested by the coast of Labrador and the strike of the pre-cambrians of which it is composed. On a gnomonic map (Fig. 39) the Arctic Sea appears as a parallel sided gulf whose shores follow this direction. Coastal features, like the long narrow peninsulas on the east end of Baffin Land emphasise it. In Alaska the trend of the coast on the gnomonc map is sharply acute to the line, which follows the strike of the land features and the rocks. This has now swung to the N.E.-S.W., whereas it is N.W.-S.E. in Labrador.

This great circle (Fig. 40) gives the trend of the coasts of Arctic America and accounts for the change in the directions of strike along them. As to its more distant continuations, parallel features in the Atlantic floor seem to be wanting. It reaches high latitudes, enters Antarctica on the 20th meridian in unknown country, but leaves it about the 100th meridian near Wild's winter quarters on the Mawson expedition, and passes behind Wilhelm II Coast. Here the trend of the line is repeated in the indentations of the isobaths off the coast. It is in Australia the most marked coincidences occur. The line passes along the west side of, and parallel to, Spencer Gulf, continues east of, but parallel to, the foliation of the Peak Downs of southern Queensland, and in the direction of the sides of the Gulf of Carpentaria, east of which its course runs. This trend is also to be seen in the folding on King

[2] C.p. T. W. E. David, Journ. R. Soc. N.S.W., 45, 1911, pp. 1-60, map.

Digitized by Google

Island and on the east side of Tasmania. It is the line of the axis of the permo-carboniferous of Northern Australia.[3] In the Pacific it is the direction of the Japan Deep, it is the line of the Peninsula of Kenai in Alaska and the island of Kodiak, and though oblique to the ' arc ' of the Kuriles, it is indicated in the alignment of some of the islands. It is also oblique to the continental shelf in the Bering Sea, which itself is transverse to the ' arc.'

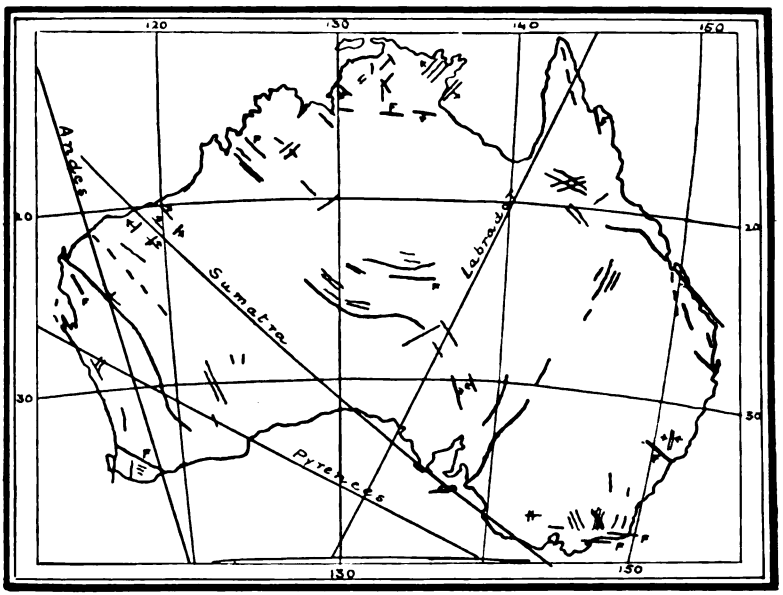


Fig. 38.—Some Australian structure lines (after T. W. E. David) with arcs of certain great circles added.

Another line of great interest is indicated in the South East Pacific by the trend of the ocean floor contours and by the alignment of some of the islands, notably the south-west, north-east tail to the Ladrones, and small groups of individuals among the Carolines (Fig. 37). It is seen also in the trend of the east coast of the Geelvink Bay in Papua, and in the lie of Timor. But there are no very precise data for the determination of the line in this quarter. Various approximations have been made, and they show it continuing along the line of the Zwarteberg and the Komsberg in Cape Colony, and in the trend of the north-east coast of South

[3] C.p. T. W. E. David, *ibid.*

Digitized by Google

America. The same trend is seen in the rocks inland near the coast, and as far to the west as the junction of the Mamore and the Madeira.[4] Here it is distinctly oblique to the trend of the Rockies, and in Mexico it scarcely modifies that trend, but it is seen in stretches of the Rio Grande del Norte, and in the trend of the

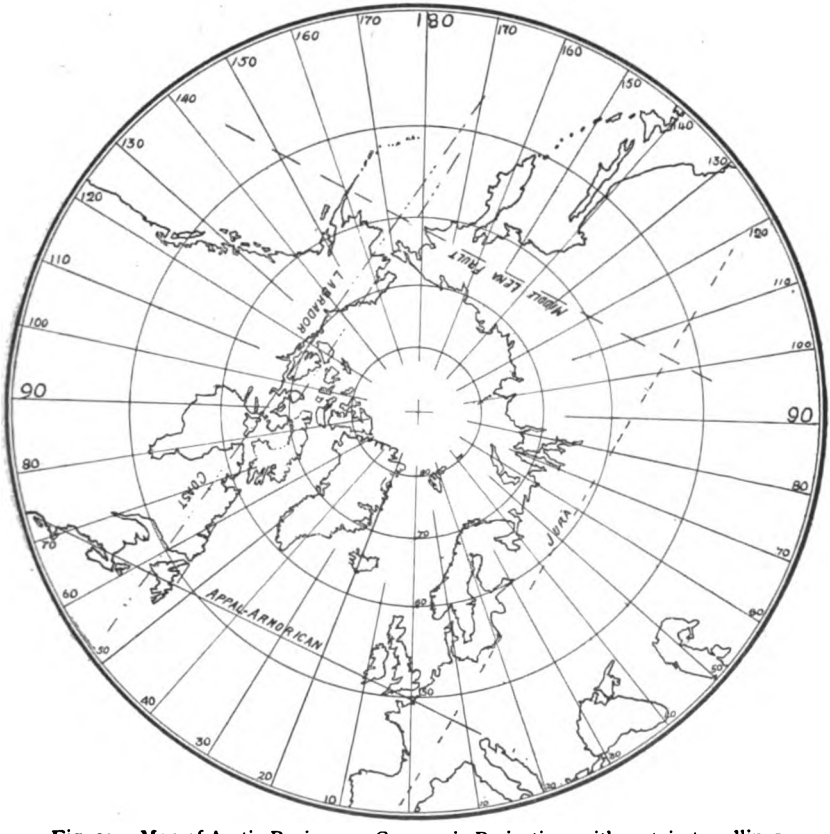


Fig. 39.—Map of Arctic Regions on Gnomonic Projection, with certain trendlines.

head of the Gulf of Mexico. Its course is east and west in the longitude of the Uinta Mountains. This circle is very nearly at right angles to that of the Sumatra trend, and the circle of Arctic America is practically perpendicular to that of the Appalachians.

[4] C.p. J. W. Evans, Q. J. G. S., 62, 1906, p. 90, map. H. Keidel, Comptes Rendus XII Congr. Geol. Internat., pp. 671-687, map.

Digitized by Google

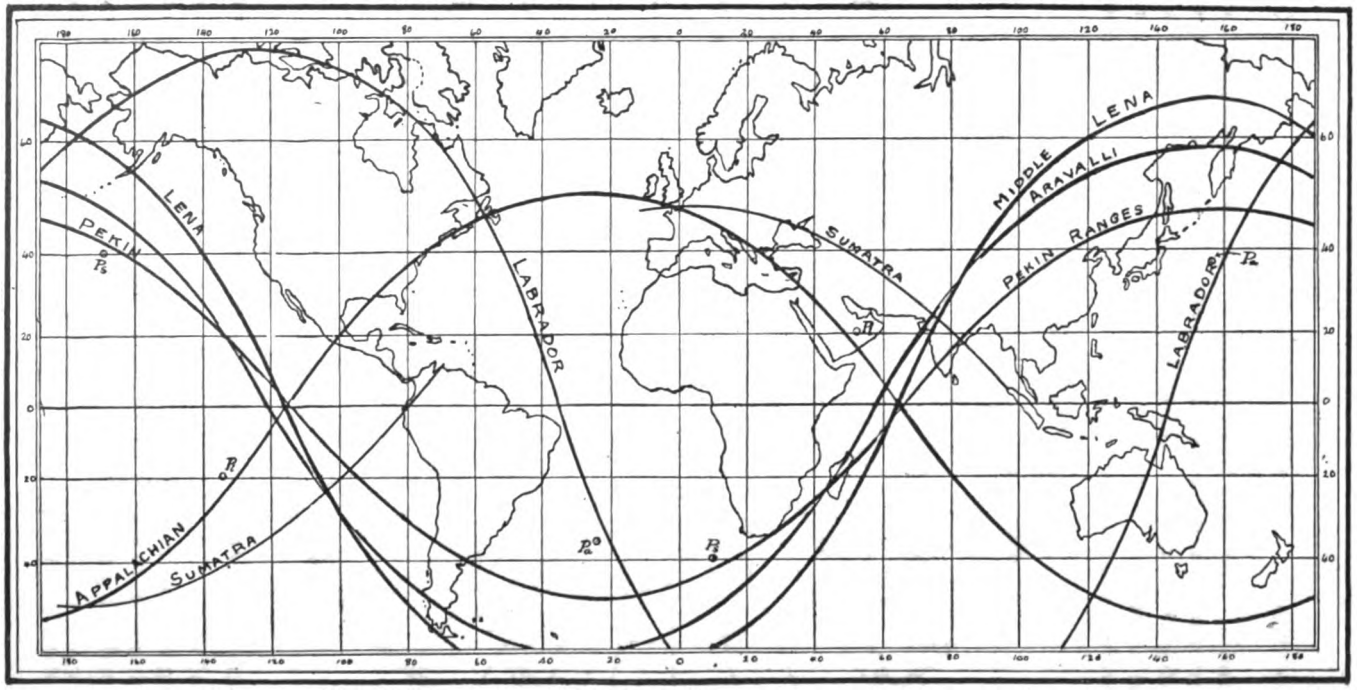


Fig. 40.—*Pa*, *Pl*, Ps are the poles of the Appalachian, Labrador, and Sumatra circles respectively. (Mercator projection).

Digitized by Google

It is not improbable that if the data on which they have been calculated were less uncertain, these circles would prove to be actually at right angles.

The figures show the general trend of certain other strike directions.

Whatever the significance of these great circles, and their reiterated coincidence with many strikes at points far apart indicates that there is a significance of great, if unknown, import, it does not lie in the individual circle but in the direction of the plane containing the circle. The direction, if the use of the term in this special sense is permissible, has an importance which does not apply to the line, *per se*. Many of the coincidences are in direction only, for they refer to areas to one side of the particular great circle, which happens to be chosen to lay out the direction, because of ease and certainty of determination at some part of its course.

Often it is a matter of a whole series of parallel lines. Thus, Arldt[5] quotes measurements of the bearings of nineteen sub-parallel lines among the Micronesian and Polynesian islands. The divergence from the mean bearing, N. 62.5° W., which is 5.5°, is easily accounted for by the distance separating the islands in which the convergence of the great circles makes itself noticeable, apart from the uncertainty in determining the bearings, which is a constant difficulty in making analyses of this kind, and will be dealt with later. The various great circles marked out by the islands converge, but they have a common node, and a great circle bisecting at right angles the arc of one of them between the nodes bisects all at right angles.

In the north-east, south-west strike characteristic of Scotland, a well marked convergence can be seen. The line of the Great Glen is not parallel to that of the Highland border, but converges with it towards the south-west, and convergence in this direction is noticeable in other lines of this system: the direction appears to become more and more nearly east and west the farther south the line. The line of the Caledonian strike also converges on that of the Highland Line, the Dalradian strike, but at a rate which is not accounted for by difference of latitude, and these are not parallel in our immediate sense.

[5] Der Parallelismus der Inselketten Ozeaniens, Zeitschr. für Erdkunde, XLI, 1906, pp. 323-346, 385-404; quoted in Arldt, Handbuch der Palæogeographie, pp, 231-232.

Digitized by Google

It is of some interest and importance to determine at what point the parallel lines converge; one is apt to expect there will be such a definite point. Attempts to fix it meet with difficulties, which are to be expected, and one finds that parallel lines cross in the same neighbourhood, but not in a point. When calculations are made of the nodes of various circles apparently belonging to the same series it becomes possible to treat statistically the variations of the position of the node.

Nevertheless it is hardly to be expected that even if the great circles indicated by trend lines are of real structural significance, they will cross in mathematical points, for the same reason that one does not expect the orthogonal systems of cracks produced in twisted glass plates will be slavishly reproduced in the structure of fractured tablelands. The lithosphere is not a homogeneous body. We may say it has heterogeneity of several orders: first minor heterogeneity, corresponding to differences of grain; second, major heterogeneity due to the properties of different rocks as a whole; and third heterogeneity on a larger scale still due to different powers of resistence of crustal blocks. The trace of an orographic feature will only show insignificant variations due to the first; its course will be undeviated on a large scale map. Even the great circles show deviations due to the second and third. Each crustal block has its own set of trends or strikes. Often these are repeated on the neighbouring blocks. The Appalachian strike occurs also in the archaeans of the Laurentian shield. It is reasonable to conclude the connection is causal if the outline of the Shield is, in part, determined by the Appalachian strike within it, for the outline will impress itself on the younger rocks moulded about it. But this is not to explain the presence of the strike in the Appalachians by the primary determining cause of it; for it was manifested in the ancient block before it was passed on to the younger. It is a case of postponing an explanation by pushing it back. The trend lines, regarded as great circles, pass from rocks of one age and features of one age to those of another, just as the same strike may appear in rocks and in orographical features of different age in the same neighbourhood. But just as one strike may be truncated by another, so the great circle trace may be lost, as the Sumatra line is lost within much (but not all) of the Indian region, to re-appear with certainty further along its direction. Just as we analyse the course of a river into longitudinal and transverse sections or, in country of more complex lineaments, into

Digitized by Google

sections following three or more dominant directions, so must we analyse orographic features in general, of which the valleys and therefore rivers, are the dominant type. Thus, the line of the Rockies as a whole is of very great interest, and it is also in the direction of a dominant strike within the mountains (Fig. 37). It is the direction of the coast of South America between Arequipa and Truxillo, an Andean trend which many writers have been puzzled to fit into their scheme of things. It is also the line of the Sa. de Ventana, and parallel lines occur in sub-Andean Brazil, Venezuela and the Argentine. It is a direction of importance in the Indian Ocean, for the ridge running north-north east from Mauritius and the east coast of Madagascar belong to it. It passes along the Andamans, corresponds to the line of the Middle Lena, and trends in the Baikal district and in north-eastern Siberia. This is a great circle whose course is most striking on an orographic globe, on which it seems unbroken from the Falklands by the Arctic to Rangoon. Again the main line of the Andes is the line of the Lesser Antilles as well as the line of strikes a little west of north in western Australia, while the Andes of Colombia and Ecuador are in the strike line of Sumatra. The Hercynian masses interrupt the courses of the great circle trend lines just as they deflect the fold arcs: but the deflections are often abrupt, as in the Central Massif of France. Their abruptness however is often reduced by the influence of topography, so that there is nothing unreasonable in preferring the view that the topographic trend passes from one line to another at a decided angle to it.

In this view the arcuate plan of mountain ranges must be modified. On most maps long stretches of mountain dominated by a single trend will show the curvature characteristic of great circles. Virgation within such stretches may be due to occurrence within them of a node common to the great circles to which the ' parallel ' arcs of the great circles belong; but since the belt of country exhibiting parallel trend is generally comparatively narrow, not more than 20° in extreme cases, the mountain curves run together at such acute angles, except where their course has been disturbed by included resistent blocks, as in Asia Minor, that the virgation is not striking, and the great mountain knots appear to be due to the crossing of trends belonging to different parallel systems. Thus, the lines of the Rockies and Sumatra cross in the Loja Knot of the Andes, while the Pasto Knot seems to be due to the interference of Andean, Rocky and other lines

Digitized by Google

The Altoplanicie of Bolivia is bounded on the north by the line of the Rockies, on the east by the Andean Line (Fig. 37). The Pamir Knot shows traces of the Himalayan (Sumatran) trend, and that of the Aravalli (this seems to belong to a convergent series which includes the parallel ranges about Pekin, the line of the Middle Lena and the line of the Rockies); and these two lines appear to form in part the boundaries of the great interior basins of Central Asia (Fig. 40). It is to the sequence of one of these trends after the other in the same orographic feature that the arcuate appearance of the great Central Asiatic ranges appears to be due. This is especially noticeable in the 'island festoons.' The Japanese Archipelago, including Saghalien, is more exactly described by two lines, one almost meridional, the other perhaps the Pekin or Aravalli line, which meet about the 140th meridian. The trend of the individual islands of the Aleutian 'arc' is altogether against its concavity westward, and the islands lie on a gnomonic map along a straight line which is tangent to the east sides of Kamchatka and Yezo, that is, on an arc of a great circle whose relations have not yet been worked out exactly. The Kuriles are in all probability in the same case. They lie across the line of the continental shelf, and three lines appear to be involved in them, of which one is probably that of the coast of Arctic America. Hobbs[6] was very near this conclusion when he exhibited one end of the arcs applied to the middle of that next to the south.

Reverting to the relationships of the lines, a whole group of difficulties in making these out is connected with the state of geological survey. It is doubtful if geological surveying can ever attain the precision of topographical survey, and if it can ever supply for the elucidation of the structure of the earth the necessary information of the same order of accuracy as the topographic results which form the basis of geodetic speculation. In the present state of knowledge we know much more about the form of the earth as a whole than about its structure on account of the great and increasing accuracy of geodetic and astronomical surveying. An immeasurably greater amount of labour is required to give geological results of the same order. That being so, it is well in discussions of the structure of the earth not to be misled by the assumed accuracy of data.

[6] The Mechanics of Arcuate Folding, Journ. Geol. XXII. 1914.

Digitized by Google

Our maps represent the features of the surface of the earth as they would appear projected on to the surface of an imaginary spheroid which approximates very closely to the figure of an earth with its surface uniformly at sea level. Slopes and surface distance due to slopes are eliminated from the map so far as it is a drawing to scale, and are only represented by a secondary set of symbols. Now, height above sea level and slope of the ground have an important effect on the position and trend of outcrops, strikes and faults, and this is the greater the gentler the dip or hade. A bed dipping uniformly at an angle of 10° would outcrop along a straight line on a map of perfectly flat country, provided the scale was not too large. But the same bed rising into a gently swelling plateau of altitude 1,000 ft., would push its outcrop forward a mile, and if the length of the outcrop on the flank of the mound was as much as 10 miles, its bearing would be altered 6°. With still gentler dips and slopes the apparent disturbance would be less easy to spot, but the real aberration from a true strike direction would be much greater. The example cited is very simple. In the endless complication of geological structure the probabilities of serious misrepresentation of structure are much greater.

What is necessary as a prerequisite to accurate study of world structure is a series of maps of the intersections of structural surfaces with the spheroid on which the map is drawn. But the methods of geological survey make this unattainable. For instance, it is customary to take strikes by means of the compass, and that method will not give bearings which can be trusted within 4°. On the other hand, no more accurate method is applicable, for it is not possible to determine by inspection of strata in the field the true direction of strike within as little as 4°, and it is of little use to measure with great accuracy the bearing of a line so roughly determined. In most cases the length of the outcrop from which the strike is measured is small. But the bearings involved in topographic mapping are useless even for the most restricted purpose if their error is greater then the thickness of a pin seen from a distance of 200 yards. If the geology is mapped by careful measurement of distance from detail topographically mapped, it gains from the base map an accuracy the compass cannot give, and it is in some degree reduced automatically to sea level; but this accuracy is largely specious as long as mountain-top outcrops are plotted as occurring at sea level whereas the geology of a sea-level section of the mountain may be quite different. In

Digitized by Google

the mapping an outcrop on a mountain top will be joined to the outcrop of the same bed at a very different level elsewhere while the intervening geology may be obscured by recent deposits, and essential links in the connection missed.

It is possible of course on the basis of detailed geological maps to make allowance for dislevelment, and at great labour to construct an approximation to a true sea-level map for the larger study of structural relations. It is still much easier and much more usual to employ a moderate scale map, such as the $\frac{1}{5}$ M map of the U.S. Geological Survey and make such allowance as one can for the effect of topography. In studying the major strikes, it is convenient to begin with the numerous lines of length 2-5 degrees of great circle, say, 100-400 miles, and it is easy to measure the bearing of these from the map to 1′ of angle. This error of measurement is well within the error of survey, which one may flatter and assume to be 10′ of angle. When one comes to produce this strike into a great circle it is like grasping a slim fishing rod in the middle and expecting the ends to remain steady in a breeze. Since parallelism of strikes is the main point of the investigation one is apt to begin with strikes which appear parallel on the map, that is, not less than 45° from the nearest node. The various circles examined, for the same reason, will mostly be within 10° of each other, and 10′ uncertainty in determining the bearing of any one of the circles means 10° of ' wobble ' in the position of the node. The nodes are therefore hard to determine even if it were reasonable to assume that they are real points. It is best to think of nodal areas rather than real point nodes, and by taking a sufficient number of circles to justify the process, after testing their intersections to make sure that they lie within a reasonably small area, fix on a point which will presumably be near the centre of the nodal area, by the ordinary methods of theory of error, and then, for the sake of making a clear diagram, correct the circles so that they all pass through this point. The circles so corrected will be found on the large scale maps to remain consistent with geology well within the error to which the geology is liable.

Maps on which have been traced numerous strike- or trend-great circles show several interesting points. There is a great density of crossing places or nodes in the Pacific, rather on the south American side, and just south of the equator, and again in the Indian Ocean rather north of the equator. Still more marked

Digitized by Google

is the tendency for numerous circles to be divergent in North America and convergent in Europe, that much fractured area, in which lie also many nodes. The same contrast lies between Asia and southern South America. Such broad features are perhaps of less interest than the grouping of the great circles into series having common nodes; for similar patterns have been obtained experimentally by Bucher[7] in the fracturing of spherical glass shells by expansion and compression. Too much may easily be made of such experimental methods, for they assume some special cause or manner of dislocation, and it is of primary importance that they be discussed, as the results of mechanical production of fold structures have been, on the basis of a complete examination

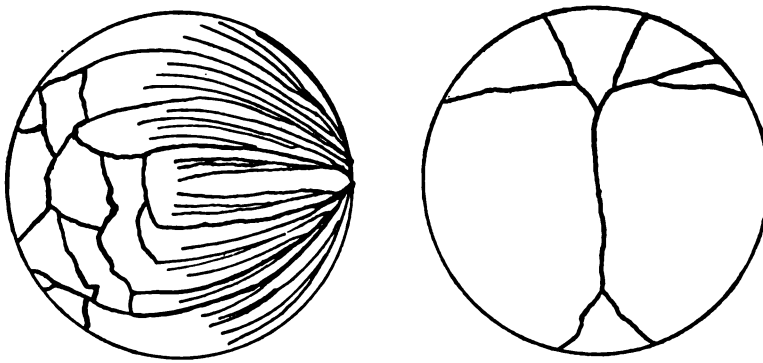


Fig. 41.—Fracture patterns on a thin spherical glass shell under tension by expansion of the interior (after Bucher).

of the plan of the deformations to be found on the surface of the earth. Nevertheless, the artificial production of the pattern of 'parallel' great circles in these 'meridional' cracks is of great interest. It is to be noted that the cracks springing from one pole or node are much more numerous than those which spring from the other (Fig. 41). If we think of the node at which converge numerous fracture lines as the 'north pole,' then at the south the meridional fracture lines seem to be continued, if at all, only by a few better marked fractures, and are surrounded by transverse cracks, not always at right angles, which are dominant. Even when meridional lines are well developed, they are by no means closely convergent at a point, but rather suggest major cracks

[7] Journal of Geology, 32, 1924, pp. 265-290.

Digitized by Google

more or less closely convergent which by repeated virgation produce a specious appearance of convergence which is by no means inconsistent with the arrangement of great circle trend lines on the earth.

Summary and Conclusion.

The attempt to discuss trends and strikes as world features in a systematic manner has been made before, notably by Elie de Beaumont.[8] His work is best known as a counterblast to the ideas of those who regarded the earth as having a hexagonal symmetry ot crystal type. He does not appear to have aimed so much at pure analysis as at establishing a pentagonal arrangement or symmetry which has been obscured by the tetrahedral hypothesis of Lowthian Green, again based upon an attempt at simplification. Elie de Beaumont's final work is described in his *Notice sur Systèmes de Montagne*[9] which is a rare work I have not been able to consult, but it is summarised in the French geological text-books. A final result of analysis will naturally be some sort of arrangement which will amount to a simplification. In all probability the great trend lines will fall into a relatively small number ot parallel systems, but there is no reason to assume that these will exhibit the symmetrical arrangement of any simple solid. If one may hazard a guess, it seems not unreasonable to imagine that nodes will be found to correspond to previous mean polar positions, but this is a pure speculation to which the only verisimilitude is given by the sub-spherical figure and the rotational motion of the earth.

In the meantime it is necessary to assess with greater care the significance in a world sense of the geological information at present available, and to avoid basing upon it conclusions which depend for support on assumptions with regard to what are really lacunae in observational knowledge. In particular, a more definite content must be given to the concept ' line,' especially when it is a matter of extrapolation, the continuation of a line from one land mass over a gap of sea to another. What does Wegener[10] mean when he says, " The Armorican Mountains . . . . make the coal deposits of North America appear as the direct continuation

[8] Ann. des Sciences Naturelles, 18, 1829, pp. 5-25, 284-416 ; 19, 1830, pp. 5-99, 177-240. C.R. 33, pp. 135. . . .

[9] Professor Gregory has now very kindly put his copy at my disposal. Still later is, *Tableau des donnees numériques qui fixent 159 cercles du réseau pentagonal* Comptes Rendus, 57, 1863, pp. 121-132.

[10] The Origin of Continents and Oceans (English Trans.), p. 52.

Digitized by Google

of the European ? " This cannot be true in any strict sense. It is a loose statement that the " (Armorican) chains stretch . . . . . westward so as to form a wild jagged type of coast . . . . . in south-western Ireland."[11] Move North America close to Europe, and the direction which is at once the Armorican and the last Appalachian trend, slides north-westward into the Laurentian region. Other loose statements, often confusing the argument, and discounting statements inconvenient to the support of the thesis in hand are frequent in work on correlation of trends.

We are not specially concerned with the validity of the theory of displacement of the continental masses. It seems to be substantially supported by other weighty and valid arguments. The analysis of geological trends in a strict sense and in a rigid manner is much to be desired. The present essay is an attempt to enforce this necessity and a beginning of its realisation. It indicates that geological trends may be of world-wide extent, a point which has often been assumed, but seldom examined. Having established that in many cases this continuity holds, it proceeds to multiply the number of lines in order to find how they are related, and whether they can be grouped into a small number of classes. There are facts encouraging the view that this may be so. Many more must be collected, and these will be able to be followed with less certainty and in less detail, as regards their wider extension, through lack of knowledge. There is not yet any foundation on which to raise any thing like a complete view of the structure of the globe which would be more than a pet notion demonstratable only to the prepared partisan. There is not even complete evidence that any one trend is associated with rocks of a determinate age or with disturbances peculiar to a special epoch. Indeed the evidence on balance leads to the opposite conclusion. We have attempted an exact examination of part of the knowledge at our disposal, and this is an essential preliminary to the elaboration of a scheme of things which has any hope of holding a permanent concept.

[11] *Ibid.* p. 53. C.p. also pp. 51-61.

Digitized by Google

Obituary.

ROBERT KIDSTON, LL.D., F.R.S.

By Dr. Donald Patton.

The news of the death of Dr. Robert Kidston, LL.D., F.R.S., came as a great shock to the scientific world. Prior to his death he was engaged on a monumental monograph on "The Fossil Plants of the Carboniferous Rocks of Great Britain," which was to run into ten parts. Part VI was nearing completion, and, setting holidays aside, Dr. Kidston was busy on the final proofs and was speeding them on for publication when he passed away suddenly on July 12th, 1924. The most difficult portion of the work had been accomplished. The pity is that the great palæontologist was not permitted to finish the task.

Dr. Kidston was born at Bishopton House, Renfrewshire. He was educated at Stirling High School and later at Edinburgh University where he studied Botany under Professor Hutton Balfour. He was intensely interested in Natural Science, and early in his career he was an enthusiastic investigator of the Scottish Arctic Alpine Flora. The Breadalbanes had always an attraction for him, but primarily as a botanist. The British Herbarium of Glasgow University Botany Department is enriched by many of his discoveries.

But it is in his work as a Palæontologist that he stands out pre-eminent, and as such he was recognised by the Geological Survey not only of Britain but of other European Countries. Special reference ought to be made to his work on "The Fossil Osmundaceae" which he carried out conjointly with the late Professor Gwynne-Vaughan, and also to his work on the Fossils of the Rhynie Cherts (plant remains discovered in these Aberdeenshire rocks by Dr. Mackie of Elgin and Glasgow). This latter investigation Dr. Kidston undertook along with Professor Lang of Manchester.

To quote from an article by Professor Bower in the Glasgow Herald, "It hardly needs to be stated that Dr. Kidston was one of the most modest of men, prepared to consider carefully opinions

Digitized by Google

often less securely founded than his own. He was generous in assistance to others and always equally generous in his criticisms. In his technique he was unrivalled. An expert photographer, he used all his art in producing illustrations that present the details even more perfectly than the eye itself could see."

In addition to his associations with Glasgow University, Dr. Kidston was connected with the leading scientific bodies of Glasgow. He was a member of the Glasgow Natural History Society from 1879 and was President of that body from 1896-99. His connection with the Glasgow Geological Society dates from 1890, and from 1917 until 1920 he was President. To both of these societies he contributed many valuable papers.

Digitized by Google

PROCEEDINGS OF THE GEOLOGICAL SOCIETY OF GLASGOW. SESSIONS, 1924-1926.

SOCIETY'S ROOMS, 207, BATH STREET, GLASGOW, 11TH DECEMBER, 1924.

The third meeting of the sixty-seventh session—*President*, Dr. G. W. TYRRELL in the chair.

Rev. S. J. R. Sibbald moved that the annual grant of £10 be made to the Library. Mr. A. McLean seconded. Mr. Sibbald announced that the books in the 1886 catalogue of the Library having been arranged *seriatim* in the book-cases, surplus copies of the catalogue might now be obtained by members *gratis*. The supplementary catalogue of 1897 would also be available for distribution to members, when the arrangement of the books catalogued in that Supplement had been completed.

Mr. Martin A. Peacock, B.Sc., read a paper on "The Petrography of Iceland." (*See this Volume*).

The President congratulated Mr. Peacock on his paper. It was interesting to note that the petrographic evidence corroborated the geological evidence of a gap in the igneous activity. The rocks of Jan Mayen which he (Dr. Tyrrell) had studied, could be correlated petrographically and in time with the later series of Icelandic lavas. Mr. Peacock's contribution to our knowledge of the nature of palagonitisation was particularly important.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207, BATH STREET, GLASGOW, 8TH JANUARY, 1925.

The fourth meeting of the sixty-seventh session—*President*, Dr. G. W. TYRRELL in the chair.

The President conveyed the congratulations of the meeting to the Society's Vice-President, Mr. Murray Macgregor, on his appointment as Assistant-Director of H.M. Geological Survey.

Mr. J. G. Roberts delivered a lecture—"Pottery Manufacture, with reference to Porcelain and its Structure."

G. W. TYRRELL.

SOCIETY'S ROOMS, 207, BATH STREET, GLASGOW, 12TH FEBRUARY, 1925.

The fifth meeting of the sixty-seventh session—*President*, Dr. G. W. TYRRELL in the chair.

Mr. W. Manson, H.M. Geological Survey, read a paper—"On an occurrence of *Sanguinolites abdenensis*, R. Eth. Jun., in N. Ayrshire." (*See this Volume*).

Mr. Macnair congratulated Mr. Manson on his discovery of the Hurlet alum shale fauna under the Dockra limestone. He (Mr. Macnair) on palaeontological and stratigraphical grounds had correlated the Dockra limestone with the Blackbyre limestone, but Mr. Manson's fauna appeared to disprove that

Digitized by Google

correlation. It should be remembered, however, that there was the possibility of a particular faunal association occurring at different horizons.

Mr. J. E. Richey said that the coal below the Dockra limestone suggested the Hurlet. He congratulated Mr. Manson on his discovery, and Mr. Macnair, that the association which he (Mr. Macnair) had traced from Fife into Renfrewshire, had been proved to extend into Ayrshire.

A paper was read by Mr. James Holmes on "The Dolerite Boss of Sithan-t-Sluain, Loch Fyne." (*See this Volume*).

Dr. Tyrrell said that this intrusion had already been mentioned in the Cowal Memoir by Dr. Clough, but Mr. Holmes was the first to describe its pegmatites. The only other coarse pegmatites of this type known to him (Dr. Tyrrell) in the West of Scotland were those in the crinanite of the Clauchland Sill, Arran. The presence of zeolites, and the other petrographic characters indicate that the rock of the 30 foot dolerite is a crinanite, probably of Kainozoic age, and to be correlated with other crinanites of the West of Scotland. Mr. Holmes' interpretation of the mechanism of intrusion was probably the correct one. Dr. W. R. Smellie was the first to describe this type of mechanism in the composite sill of S. Bute.

Mr. J. E. Richey said that the intrusion was similar to occurrences of a larger scale in Ardnamurchan. Dr. Clough had noticed the pegmatite, but referred to it as "veins." Did the pegmatite circle right round the intrusion in plan? In the ring-dyke of eucrite in Ardnamurchan pegmatites occur in strings parallel to the outer margin, pointing to vertical walls in the intrusion. What was the felspar in the rock? If bytownite, the rock was probably eucrite. Was the dyke described by Mr. Holmes a tongue from the intrusion, or a north-wester?

Mr. Holmes, in reply, said that the pegmatite went right round the intrusion. The felspar of the rock was bytownite, that of the pegmatite mainly labradorite. The dyke was simply a tongue, protruding from the intrusion.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207, BATH STREET, GLASGOW, 12TH MARCH, 1925.

The sixth meeting of the sixty-seventh session—*President*, Dr. G. W. TYRRELL in the chair.

A paper was read by Prof. J. W. Gregory, D.Sc., F.R.S., on "The Moraines and Glacial Sequence in the South-West of Scotland." (*See this Volume*).

Mr. E. M. Anderson said that shells in the boulder clay could be accounted for by the passage of ice from the West, over a pre-existing marine bed. In N. Ayrshire striae and drumlins, and the disposition of crag-and-tails seemed to indicate movement from N.E. to S.W. A set of E.-W. drumlins was also present. There was evidence in a remodelled drumlin that the E.-W. was the earlier. He could not agree with Prof. Gregory's theory of the submarine deposition of boulder-clay.

Mr. J. E. Richey said that at a certain locality in N. Ireland shelly boulder-clay occurred at such a height above sea-level as to render it difficult to account for by submergence. It was probable that the Cowden Glen deposits were formed in a lake, because of the presence of land-plants. The other theory demanded a too rapid oscillation.

Digitized by Google

Mr. Steele said that at one time in Garvel Park, Greenock, there was a section which showed Arctic shells in a typical tough till; this deposit passed up into sandier beds, stained black, perhaps by carbonaceous matter from decaying sea-weed; this horizon contained a warmer fauna.

Mr. G. Ross said that he had found moraines on the north face of Nutberry Hill and Priesthill in Lanarkshire. The land surface on the flat ground consists of boulder-clay with little drift; above the 800 ft. contour drift is abundant, with one or two moraines. To the west of this locality, also, below the 800 ft. contour, the boulder-clay is sculptured drumlin-fashion, and has no drift. These facts are difficult to account for on a land-ice theory, as one would expect to find retreat phenomena.

Dr. Tyrrell said that in Spitsbergen there was unequivocal evidence of the formation of till on land. It was indistinguishable from the till of the Glasgow district. Glaciers pass down over the shell and tundra-bearing raised-beaches, covering them with a mantle of boulder-clay. He had seen ice in Klasbillen Bay drift out and in frequently during a period of several days; this ice coming into contact with rocks, would produce scratches of the kind described by Prof. Gregory. He thought Ayrshire a too distant source for the travelled analcite-basalt of the Severn; the Clee Hills in Shropshire were a more probable source.

Prof. Gregory, in reply, said that the trend of the discussion showed there was a tendency to explain the fossils of the till by the theory that they had been dragged up from the bottom of the sea. The deposits to which Mr. Richey had referred were probably those of the Three Castles Mountain, Dublin. As at Clava, a British Association Committee found that the evidence there pointed to subsidence. If the theory of isostacy is to be retained, we must admit the possibility of such movements under ice-pressure. Since the hypothesis of an ice dome in central Ireland had been discarded, it was difficult to see where the ice could have come from if it were land ice, as evidence all over the country indicated movement from the west. It could not be from Arran as there were no traces of Arran granites. Some agent other than land ice was required to explain the criss-cross and concentric striation found at Lugton. He had been on Nutberry Hill and Priesthill, but had not seen the moraines mentioned by Mr. Ross. From Mr. Ross's description they appeared to be comparable to those of the Avon. With regard to the Spitsbergen boulder-clay, Mr. Lamplugh was of opinion that it had been formed under the sea; the numerous raised beaches indicated that Spitsbergen was rising rapidly. There is no boulder-clay in the Antarctic, but the deposits on the floor of the Ross Sea will form typical boulder-clay when dry. He agreed with Dr. Tyrrell that there was a tendency to ascribe travelled material to sources too far distant, but the association of Criffell granite with analcite-basalt on the Severn indicates the south-west of Scotland as probably the correct source. The interstratification of land and marine fossils is due to isostatic oscillation. There is no more evidence for regarding the boulder-clay fossils as extraneous, than for regarding as extraneous the fossils of any other shell-bed. Prof. Garwood and he had described the uplift of shells by glacier, but to nothing like the same extent as in the boulder clay, and the shells did not retain the epidermis, as is usually the case with the boulder-clay fossils.

Mr. W. B. Lawson was elected student associate of the Society.

G. W. TYRRELL.

Digitized by Google

SOCIETY'S ROOMS, 207, BATH STREET, GLASGOW, 9TH APRIL, 1925.

The seventh meeting of the sixty-seventh session. Dr. G. W. Tyrrell delivered part 2 of his Presidential Address—"Igneous Action and Earth Movement—the Aftermath of the Caledonian Revolution."

The trend of the Caledonian Mountains was from N.E.-S.W. In the intervening valleys the conglomerates of the O.R.S. were laid down. Faulting along the boundaries of these valleys in Middle O.R.S. time produced rift valleys, of which the most notable example is the Midland Valley of Scotland. Evidence in faulting, and in unconformities in local basins of deposition shows that the subsequent history of this valley was one of breaking down and subsidence. The E.-W. Hercynian folding of late Carboniferous times in the south of England and Wales is probably represented by the set of E.-W. faults in the Midland Valley. The N.W.-S.E. faults and dykes are to be correlated with Kainozoic movements. Carboniferous igneous activity appears to be earlier than the E.-W. faulting. In the Kristiania district there is a rift valley, in structure and sequence of igneous rocks similar to the Midland Valley. It differs in being bounded on both sides by Archean, and having a floor of older folded Palaeozoic rocks ranging up to Downtonian. There is complete absence of Carboniferous sediments, and Devonian is doubtfully present. In the igneous history of the Midland Valley, basalts of slightly alkaline character were the earliest eruptives. Post-Calciferous-Sandstone lavas are olivine-basalts of Hillhouse type. Millstone Grit lavas are generally altered to bauxitic clays but when fresh are of Dalmeny type. Permian igneous rocks of the Midland valley are chiefly intrusions, analcite- and nepheline-bearing. During Carboniferous times, therefore, the igneous rocks of the Midland Valley grew richer in basic minerals and in felspathoids. Essexite, larvikite, and lardalite plutonics, with rhomb-porphyry lavas, occur at the base of the Kristiania sequence, then quartz-syenites and orthoclase-rich granites with no lavas. In Scotland there are no plutonic rocks comparable with those of Kristiania; erosion has probably not gone far enough to expose them. The lavas and minor intrusions show striking correspondence in the two regions. There are minor mineralogical differences; anorthoclase is absent in the Scottish rocks, and in the Kristiania felspathoid rocks analcite is subordinate. This is possibly explained by the fact that in Scotland the magma was erupted into wet unfolded rocks, therefore analcite formed instead of nepheline. Regarding the age of the Kristiania rocks all that can be definitely said is that they are post-Silurian. Probably they are slightly older and cover a shorter period of time than the rocks of the Scottish Midland Valley. The E.-W. quartz-dolerite dykes of Scotland are alien to the Midland Valley series. Although basic they are over-saturated; their distribution is wider (they occur in the S.W. Highlands) and they are later than the E.-W. faults. They are therefore later than the Midland Valley series, and probably represent the aftermath of the Hercynian movements i.e. the continental phase following these movements.

G. W. TYRRELL

SOCIETY'S ROOMS, 207, BATH STREET, GLASGOW, 8TH OCTOBER, 1925.

The first meeting of the sixty-eighth session—*President*, Dr. G. W TYRRELL in the chair. William Mackie, M.A., M.D., LL.D., was elected a member of the Society.

Digitized by Google

Mr. J. E. Richey, H.M. Geological Survey gave an account of the Igneous Geology of Ardnamurchan.

The country to the east of the peninsula consists of psammitic schists; these schists are succeeded in the south-east by mesozoic sediments, which are transgressed by basalt lavas. Later come transgressive agglomerates and quartz-dolerite, then cone-sheets encircling the peninsula and dipping towards the centre at about 40 degrees. Later than the cone-sheets and concentric with them are the ring-dykes of the first period; the second series of ring-dykes conforms to a different centre.

Dr. G. W. Tyrrell, in thanking Mr. Richey for his lecture, said that the exposition of ring-structures was one of the most remarkable contributions to Vulcanology of recent years. They were first demonstrated in the Devonian of Glencoe by Messrs. Clough and Bailey. Occurrences had been recorded from the Devonian and early Carboniferous of the Kristiania district. The Mull ring-structures were the most outstanding examples in Kainozoic igneous rocks. In examining a part of Arran this summer he came to the conclusion that the various igneous rocks of the so-called " central vent " are arranged in discontinuous concentric rings, with screens of country rock separating the rings, and a brecciated centre due to the explosive properties of the final acid magma. The Arran occurrences thus paralleled those of Mull and Ardnamurchan. He would like to ask Mr. Richey for some details about the quartz-olivine-dolerite he had mentioned, as the association of quartz and olivine was an interesting petrological phenomenon.

In reply Mr. Richey said that the quartz-olivine-dolerite was a quartz-dolerite with olivine in the earliest crystallised portion. Quartz-gabbros containing olivine were also present: a later acid magma had reacted with the earlier crystallised portion, producing a hybrid.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207 BATH STREET, GLASGOW, 12TH NOVEMBER, 1925.

The second meeting of the sixty-eighth session—*President*, Dr. G. W. TYRRELL in the chair. Election of office-bearers:—

Vice-President (for three years)—Arthur E. Shute.

Members of Council (for three years)—Dr. M. A. Peacock; Wm. McLean; W. J. McCallien, B.Sc.; B. H. Barrett, M.A., B.Sc.; J. E. Richey, M.C., B.A.

Reports of the Council, Library, and Finance were read by the Secretary, Librarian, and Treasurer. In commenting on these reports, Dr. Tyrrell said that in connection with the policy of bringing distinguished strangers to the meeting, he wished to announce that he had secured Dr. Arthur Holmes for the December meeting, 1926. The adoption of the reports was moved by Mr. McLean, and seconded by Mr. Steele.

Miss Eliz. Brock was elected to the membership of the Society, and Messrs. Robt. Pentland and Duncan Leitch were elected associate Members.

Mr. Shute gave notice of motion to be made at the December Meeting, that the annual grant of £10 be made to the Library.

Mr. A. Stevens, M.A., B.Sc., Lecturer in Geography, Glasgow University, then read a paper on " Some Geometric Lines in Relation to Earth Structure." (*See this Volume*).

G. W. TYRRELL.

Digitized by Google

SOCIETY'S ROOMS, 207, BATH STREET, GLASGOW, 10TH DECEMBER, 1925.

The third meeting of the sixty-eighth session—*President*, Dr. G. W. TYRRELL in the chair.

Mr. T. Baird, M.A., and Mr. E. W. Bell were elected associate members of the Society.

Mr. Shute moved that the annul grant of £10 be made to the library.

A paper was read by Mr. W. J. McCallien, B.Sc., on "The Structure of S. Knapdale, Argyll." (*See this Volume*).

Mr. M. Macgregor complimented Mr. McCallien on his paper, and said he looked forward to the time when Mr. McCallien should have finished his work on the Kintyre area. Had Mr. McCallien found any evidence of thrusts or slides at the junction of the Ben Lui Group with the Erins Quartzite? Mr. J. E. Richey asked if Mr. McCallien had found the Stronchullin Phyllites similar to the Ardrishaigs along their respective junctions with the Erins Quartzite? Mr. J. Holmes said that farther north on the other side of L. Fyne, metamorphic zones were bounded by faults.

Mr. McCallien in reply, said that an examination of the junction of the Ben Lui Schists was without the scope of the present paper. He had not dealt with rock-types; his conclusions were based on structures observed in the field. There were no faults bounding metamorphic zones in the Tarbert area; the transitions were everywhere gradual.

Mr. B. H. Barrett, M.A., B.Sc., read a paper on "The Petrography of the Shieldhall Sands." (*See this Volume*).

Dr. Tyrrell said that the presence of less than one per cent. of heavy residue in the sands indicted that they are not of glacial origin. The pebble analysis showed a strange abundance of Highland rocks—30 per cent. was about the average. In his experience the higher the horizon in the boulder clay, the higher the content of Highland pebbles, owing to the accumulation of the pebbles of the earlier deposits in those of the later glaciation. Mr. M. Macgregor said that Mr. Barrett's work was useful in supplementing the observations and records of the Geological Survey. Mr. J. E. Richey expressed the hope that Mr. Barrett would undertake the petrographic investigation of the glacial lake terraces at Eaglesham, with a view to determining the origins of the materials.

G. W. TYRRELL.

SOCIETY'S ROOMS, 207, BATH STREET, GLASGOW, 14TH JANUARY, 1926.

The fourth meeting of the sixty-eighth session—*President*, Dr. G. W. TYRRELL in the chair. Mr. W. Q. Kennedy was elected an ordinary member of the Society.

Mr. J. M. Wordie, M.A., St. John's College, Cambridge, delivered a lecture on the Geology of Jan Mayen.

Jan Mayen is situated some distance from the east coast of Greenland and from the submarine bank which connects Iceland and the Faroes with Scotland. The geological history of the two main (north and south) dvisions of the island showed the same general sequence of events—trachyte, trachybasalt, tuffs and sills; the most recent phase was the formation of small secondary craters with only single eruptions. Associated water-formed conglomerates indicated climatic conditions similar to those of the present day. The evidence

Digitized by Google

suggested a quaternary age for the rocks exposed, although the mature outlines of the topography at the south end suggested a greater age. In recent years conspicuous changes have taken place in the coast line. Accumulations of sand, due to changes of current depositing material against natural barriers (e.g. lava-flows) have involved even the high *klippen*, have given rise to conspicuous features like the South Lagoon, and connected Egg Bluff, once an island, to the mainland.

Dr. Tyrrell said that he had made a petrographic examination of Mr. Wordie's Jan Mayen rocks. He found them analogous to those of oceanic islands, e.g. Ascension and Samoa. They are similar to the rocks of the later series of Iceland, a fact which supports Mr. Wordie's view of their quaternary age.

Dr. M. A. Peacock asked if it was clear whether the trachyte of Bombelles Mountain was a lava? Might it not be an intrusion? In shape it was similar to the rhyolite mountains of Iceland, which were intrusions.

Mr. J. Holmes said that Mr. Wordie's excellent lantern slides had suggested one or two points. Was the drift timber shown in one of the slides likely to be of Siberian origin? Nansen had met with Siberian drift wood in Greenland, and had inferred from that discovery that it should be possible to drift a ship across the pole.

Raised beaches and erosion forms shown on the slides suggested a preglacial rather than a postglacial age for the island. The small secondary craters of the last phase seemed to be explosion craters.

Mr. Wordie, in reply, said that the trachyte of Bombelles Mountain might be intrusive. He did not think that the volcanic cones of the north end, with their Vesuvius-like forms could have suffered glacial erosion; the remainder of the island might be preglacial.

Mr. W. R. Flett, B.Sc., communicated a note by Mr. W. E. Swinton, B.Sc., on a bone of the Woolly Rhinoceros from the sand quarry at Hungryside, Torrance. The bone was exhibited. Mr. Flett gave a short description of the deposit in which the bone was found. (*See this Volume*).

Mr. Ludovic Mann emphasised the importance of the discovery of the bone and referred to notices in early Transactions of the Wernerian Society of two discoveries of rhinoceros bones in the region of the Forth and Clyde Canal. He inferred from these discoveries that Palaeolithic Man had hunted the companion of the mammoth in Scotland. There were no definite traces of Man's presence; probably they had all been swept away, as there were no limestone caves to preserve remains. It was important to know the height of the deposit above O.D., in order to correlate its formation with the oscillations of surface which coincided with the genial interglacial episodes.

Rev. J. D. McCulloch communicated a note on the occurrence of Kentallenite Boulders in the neighbourhood of Greenock. (*See this Volume*).

G. W. TYRRELL.

SOCIETY'S ROOMS, 207, BATH STREET, GLASGOW, 11TH FEBRUARY, 1926.

The fifth meeting of the sixty-eighth session—*President*, Dr. G. W TYRRELL in the chair.

Dr. Wm. Mackie read a paper on "The Apatites in Sedimentary Rocks as Indicators of the Amount of Atmospheric Carbonic Acid in the Periods of Deposit." (*See this Volume*).

G. W. TYRRELL.

Digitized by Google

ABSTRACT

OF THE

TREASURER'S ACCOUNTS.

Digitized by Google

ABSTRACT OF TREASURER'S ACCOUNTS FOR THE YEAR ENDING 30TH SEPTEMBER, 1925.

CASH ACCOUNT.

RECEIPTS.

To Balance on hand 30th Sept., 1924 :—			
Balance in Bank	£134 7 0		
Cash on Hand	4 12 8		
		£138	19 8
,, Subscriptions:—			
Ordinary Members—86 at 15/-	£64 10 0		
Arrears—6 at 15/-	4 10 0		
Lady Members—6 at 10/-	3 0 0		
Associate Members—8 at 2/6	1 0 0		
		£73	0 0
,, Interest on Investments:—			
War Stock including Cowie Prize Fund	£13 8 9		
Funding Loan (James Neilson)	3 17 0		
		£17	5 9
,, Deposit Receipt Interest		£1	6 2
,, Exchequer Bonds Realized, including Cowie Prize Fund		£250	0 0
		£480	11 7

EXPENDITURE.

By Library:			
Geological Magazines		£1	10 0
,, *Transactions*, Vol. XVII, pt. 2.:			
Cost, including Illustrations	£160 10 0		
,, *Less*:—			
Glasgow University for separates of Authors' Papers £26 13 6			
Mitchell Library for 40 copies 3 12 4			
Authors' copies 2 0 0			
Sales by Librarian 2 0 0			
	£34 5 10		
		£125	14 2
,, Subscriptions:			
Palaeontographical Society		£1	1 0
Scottish Marine Biological Association		1	1 0
Natural History Society (for use of Lantern)		1	1 0
,, Cowie Prize Fund:			
Glasgow University, Interest to Martimas, 1924	£2 17 6		
,, Royal Technical College, Interest to Martimas, 1924	2 17 6		
		£5	15 0
,, Administration:			
Printing and postages	£18 0 4		
Rent, Lighting, and Attendance	17 0 0		
Hon. Secretaries' and Treasurer's Expenses	2 8 1		
		£37	8 5
By Funds re-invested in War Stock, 1929-1947, including Cowie Prize Fund		£250	0 0
Outlays on Same		5	2 2
,, Cash in Hand—Balance in Bank	£51 2 10		
Cash on Hand	16 0		
		£51	18 10
		£480	11 7

Digitized by Google

LIFE SUBSCRIPTION ACCOUNT.

Sept. 30, 1925.—To Balance on Hand	£245 10 0	Sept. 30, 1924.—By Balance from Last Account ..	£245 10 0
	£245 10 0		£245 10 0

C. R. COWIE'S PRIZE FUND.

Sept. 30, 1925.—To Glasgow University, one half Interest to Martimas, 1924	£2 17 6	Sept. 30, 1924.—By Balance from Last Account	£103 15 0
,, Royal Technical College, one half Interest to Martimas, 1924 ..	2 17 6	,, One Year's Interest	5 15 0
,, Outlay in Re-investment	2 0 0		
,, Balance to Credit	101 15 0		
	£109 10 0		£109 10 0

BALANCE SHEET.

To Life Subscription Account	£245 10 0	By Investments:			
,, Cowie Prize Fund	101 15 0	War Stock, 1929-1947, including Cowie Prize Fund			£250 0 0
,, Capital	554 13 10	Funding Loan, 1910-1990 (James Neilson) ..			£100 0 0
		,, Property:			
		Books	£440 0 0		
		Furniture, Bookcase and Microscope	60 0 0		
				£500 0 0	
		,, Balance in Bank	£51 2 10		
		,, Cash in Hand	16 0		
				£51 18 10	
	£901 18 10				£901 18 10

GLASGOW, 28*th October*, 1925:—Examined, compared with relative Vouchers and Securities, and found correct, the Balance in Treasurer's hands being Sixteen Shillings sterling.

ARCH. MACINTYRE, F.S.A.A., }
ALEXANDER MCLEAN. } Auditors.

Digitized by Google

THE GEOLOGICAL SOCIETY OF GLASGOW.

Office-Bearers for Session 1925-1926.

President—

G. W. Tyrrell, A.R.C.Sc., Ph.D.

Vice-Presidents—

J. G. Roberts.
M. Macgregor, M.A., B.Sc.
Arthur Shute.

Members of Council—

Ethel D. Currie, B.Sc., Ph.D.
D. McVean, M.A., B.Sc.
J. Holmes, B.Sc.
H. Priestley.
R. B. Anderson.
D. N. MacArthur, Ph.D.
A. McLean.
M. A. Peacock, B.Sc., Ph.D.
B. H. Barrett, M.A., B.Sc.
W. J. McCallien, B.Sc.
J. E. Richey, M.C., B.A.
W. McLean.

Honorary Treasurer—

James L. Begg, The Elms, Mount Vernon.

Honorary Librarian—

Rev. S. J. Ramsay Sibbald, D.D., 33, Lilybank Gardens, Glasgow.

Honorary Secretaries—

David B. Duncanson, B.Sc., The Training College, Jordanhill, Glasgow.
John Weir, M.A., Ph.D., Geology Department, The University, Glasgow.

Digitized by Google

LIST OF MEMBERS

(As at 12 Jan., 1927).

Non-Resident Honorary Member.

Year of Election.

1917. Harker, Alfred, M.A., F.R.S., St. John's College, Cambridge.

Resident Honorary Members.

1902. Horne, John, LL.D., F.R.S., 20 Merchiston Gardens, Edinburgh.
1907. Murdoch, Mrs. J. B., Capelrig, Dunblane.
1902. Peach, B. N., LL.D., F.R.S., Geological Survey Office, Edinburgh.
1909. Smith, John, Dykes, Dalry, Ayrshire.

Ordinary Members.

[An asterisk (*) indicates a Life Member.]

1905. Anderson, E. M., M.A., B.Sc., H.M. Geological Survey Office, 33 George Square, Edinburgh.
1923. Adams, John, 362 St. Georges Road.
1922. Anderson, Robert, 115 Oran Street, Glasgow.

1919. Bailey, E. B., M.C., B.A., F.G.S., 33 George Square, Edinburgh.
1925. Baird, T., M.A., Schoolhouse, Baldernoch, Torrance.
1894. Barr, Archibald, D.Sc., LL.D., Mugdock, Milngavie.
1924. Barrett, B. H., M.A., B.Sc., 26 Carrington Street.
1905. *Begg, James L., 13 Weirwood Park, Bailleston.
1925. Bell, E. W., 6 1st Avenue, Renfrew.
1923. Blair, James, 7 Ardoch Gardens, Cambuslang.
1914. Borland, James, 8 Barns Street, Ayr.
1912. Brodie, Matthew S., 60 Barassie Terrace, Troon.
1925. Broch, Margaret, Spittal Cottage, Dumbarton.
1906. Carruthers, R. G., F.G.S., H.M. Geological Survey Office, 33 George Square, Edinburgh.

Digitized by Google

1912. *Conacher, Harry R. J., Horsewood Road, Bridge of Weir.
1900. *Cozens, Samuel F., Salem, Skelmorlie.
1924. Cullen, Alex., 14 Hamilton Park, Glasgow.
1920. Currie, Ethel., M.A., B.Sc., Ph.D., 3 Hazelwood Road, Dumbreck.

1907. Donald, W., 16 Lilybank Gardens.
1881. *Dougan, John, 27 Smith Street, Hillhead, Glasgow.
1920. Dow, Eric, 9 Park Quadrant.
1895. Dron, R. W., M.Inst.C.E., 11 West Regent Street, Glasgow.
1923. Drummond, Jean, 1 Rosemount Terrace, Ibrox.
1913. *Duncanson, David B., B.Sc.,(Lond.), 19 King Edward Road, Jordanhill, Glasgow.
1901. Du Toit, Alex. L., B.A., F.G.S., Irrigation Department, Pretoria, South Africa.
1914. Edwards, E. J., M.Sc., Royal Technical College, Glasgow.
1901. Faill, John, 7 Winton Drive, Kelvinside, Glasgow.
1911. Falconer, J. D., M.A., D.Sc., F.G.S., F.R.S.E., 58 Prince of Wales Road, Battersea, London.
1915. Fletcher, W., Woodlea, Bothwell Road, Hamilton.
1915. Fraser, J. M., 169 Berkeley Street, Glasgow.
1898. *French, Thomas, 1 Kelvinside Terrace, Kelvinside, Glasgow.

1919. Gardiner, Alex., 134 Bath Street, Glasgow.
1887. Gardner, John, 65 Great Clyde Street, Glasgow.
1919. Garven, Alex. B., Dunblair, Kilmarnock.
1873. *Gilmour, Thomas, M.D., Port Ellen, Islay.
1877. *Graham, M. M., 21 Bath Street, Glasgow.
1904. *Gregory, John Walter, D.Sc., F.R.S., F.G.S., Professor of Geology, Glasgow University.

1923. Haddy, John (Assoc.), 106 Beechwood Drive, Broomhill.
1915. Hamilton, James, 121 St. Vincent Street, Glasgow.
1913. *Harrison, John V., B.Sc., 34 Rowallan Gardens, Glasgow.
1921. Hay, Robert, Royal Technical College.
1923. Hayward, Alex., 3 Stanhope Street, St. Rollox.
1912. Herdsman, W. H., 141 Bath Street, Glasgow.
1923. Hodge, Robert, 312 Keppochhill Road.
1923. Holmes, James, B.Sc., 19 Denholm Street, Greenock.
1908. Hunter, George, M.Inst.M.E., Mining College, Wigan.

Digitized by Google

1901. Hunter, William, Rosemount, Ledard Road, Langside, Glasgow.
1903. Hurll, Mark, Drumchapel.

1911. *Innes, Peter, 5 Ibrox Place, Paisley Road (West), Glasgow.

1917. Keay, Miss G. L., 31 Melville Street, Glasgow.
1924. Kennedy, W. Q., Rozelle, Bridge of Weir.
1908. Kerr, David, Lynnewood, 140 Bo'ness Road, Grangemouth.
1882. King, Robert C., Solicitor, Ledcameroch, Kilwinning.
1907. *Knight, James, M.A., D.Sc., 9 Douglas Gdns., Uddingston.

1925. Leitch, Duncan, 223 New City Road.
1908. Leitch, P. Arthur, Haxtonn, Bothwell.

1916. *MacArthur, D. N., B.Sc., Ph.D., 28 Grafton Street, Glasgow.
1899. M'Creath, George W., M.E., 208 St. Vincent Street, Glasgow.
1904. M'Creath, William, C.E., M.Inst.M.E., 208 St. Vincent Street, Glasgow.
1919. M'Gill, Dr. James, Coylton, Ayrshire.
1910. M'Gregor, Murray, M.A., B.Sc., H.M. Geological Survey, 33 George Square, Edinburgh.
1904. Macintyre, Arch., F.S.A.A., Muirbrow Chambers, Hamilton.
1925. Mackie, Dr. W., 40 Montgomerie Street.
1924. McCallien, W. J., B.Sc., Geology Dept., University.
1923. McLean, William, 1a Ronald Street, Coatbridge.
1903. *M'Lean, Alexander, 466 St. George's Road, Glasgow.
1917. MacMillan, Robert, M.A., B.Sc., 22 Eglinton Terrace, Ayr.
1895. Macnair, Peter, F.R.S.E., F.G.S., Art Galleries and Museum, Kelvingrove, Glasgow.
1920. Melville, Edward, Agricultural College, Glasgow.
1922. Miller, William, 30 Brandon Street, Motherwell.
1897. *M'Neil, Charles, 1 University Gardens, Glasgow.
1914. M'Queen, David P. H., 7 Stewartville Gardens, Wishaw.
1914. M'Vean, Duncan A., M.A., 213 Crow Road, Broomhill.
1883. M'Whirr, John, J.P., 3 St. John's Road, Cathcart, Glasgow.

1917. Main, James, Bonnybridge.
1887. Main, John, F.G.S., 24 Marlborough Avenue, Partick.

Digitized by Google

1894. Mann, Ludovic M'Lellan, F.S.A.(Scot.), 183 West George Street, Glasgow.
1915. Miller, Alfred G., Norwood, Strathmore Road, Hamilton.
1881. *Mitchell, G. A., 5 West Regent Street, Glasgow.
1904. *Moore, Quintin, 10 Wedderlea Drive, Cardonald.
1877. Moore, Robert T., D.Sc., C.E., 142 St. Vincent Street, Glasgow.
1908. *Morrison, James, 24 Rowand Avenue, Giffnock.
1900. *Muirhead, John, 13 St. John's Drive, Pollokshields, Glasgow.
1898. Munro, Alexander, 1 Blythswood Square, Glasgow.
1923. Munro, James D., 3 Leyden Street, N.W.
1894. *Murdoch, Robert, 91 Maxwell Road, Pollokshields, Glasgow.
1907. *Murdoch, J. A. W., Capelrig, Dunblane.
1870. *Murray, David, LL.D., 169 West George Street, Glasgow.
1907. Murray, Andrew G., c/o Brownlie, Watson and Beckett, 225 West George Street, Glasgow.

1907. Neilson, Miss Agnes T., 41 West Cumberland Street, Glasgow.
1894. *Neilson, James, 116 Bishop Street, Port-Dundas, Glasgow.

1915. Patton, Donald, M.A., B.Sc., 9 Thornwood Gardens, Broomhill.
1924. Peacock, Martin, B.Sc., Ph.D., L.R.A.M., 7 Cathkin Road, Langside.
1925. Pentland, Robert, 5 Porter Street, Bellahouston.
1920. Phemister, James, M.A., B.Sc., 42 Boswell Avenue, Edinburgh.
1923. Pirret, John, 20 Ward Street.
1910. *Preston, Frank A. B., 27 Ferguson Avenue, Milngavie.
1910. Priestly, H., 8 Glenview, Paisley.

1921. Ramsay, D. G., 33 George Square, Edinburgh.
1873. Rankine, David, C. E., 238 West George Street, Glasgow.
1902. Reoch, James W., Anglo-Persian Oil Co., 23 Great Winchester Street, London.
1922. Richey, James E., M.C., B.A., 33 George Square, Edinburgh.

Digitized by Google

1923. Riley, John, 312 Keppochhill Road.
1911. Roberts, J. G., Trees Cottage, Barrhead.
1914. Robinson, P. J., A.M.Inst.C.E., Tweedale, Hamilton.
1910. Romanes, Mrs. J., Orchard House, West Byfleet, Surrey.
1921. Ross, G., 33 George Square, Edinburgh.
1875. *Rottenburg, Paul, LL.D., Holmhurst, Dowanhill Garden, Glasgow.

1923. Scott, William, 63 Elder Park Street, Govan.
1897. Shanks, Arch., 5 Green Lodge Terrace, Greenhead, Glasgow.
1893. *Sharp, John Grant, 127 Great Hamilton Street, Glasgow.
1910. Shute, Arthur E., 4 Holyrood Crescent (West), Glasgow.
1887. *Sinclair, William, 47 Oswald Street, Glasgow.
1911. Smellie, Wm. R., M.A., D.Sc., Ardene, Mossend.
1908. Smith, Duncan, F.F.S., Laurelbank, Arkleston Road, Paisley.
1920. Sibbald, Rev. Ramsay, D.D., 33 Lilybank Gardens.
1926. Simpson, Dr. D., Librarian, University, Aberdeen.
1917. *Spiers, A. A. Hagart, D.L., J.P., Elderslie, Renfrewshire.
1896. Stark, James, 13 Princes Gardens, Partick, Glasgow.
1881. Steel, James, 37 Prince Edward Street, Crosshill, Glasgow.
1918. Stein, Norman, Castlecary, by Bonnybridge.
1919. Stein, Lt.-Col. Allan, M.C., Castlecary.
1923. Steven, Alex., Technical School, Kilmarnock.
1912. Stevens, Alexander, M.A., B.Sc., Geological Department, University.
1919. Stewart, Edward J. A., M.A., B.Sc., 8 Manor Road, Jordanhill.
1878. Stewart, Thomas, Gen. Estate Chambers, Adderley Street, Capetown, South Africa.
1923. Stobo, Emily, B.Sc., 43 Dudley Drive, Hyndland.
1914. Sutherland, J. R., M.Inst.C.E., Engineer's Office, 45 John Street, Glasgow.
1920. Swinton, William E., B.Sc., F.G.S., British Museum, Cromwell Road, London.
1923. Syme, Victor, 362 St. George's Road.

1906. Tyrrell, G. W., A.R.C.Sc., F.G.S., Ph.D., Geological Department, Glasgow University.
1907. Waddell, A. W., M.E., 18 Kensington Gate (West), Glasgow.

Digitized by Google

1917. Wallace, A., 1 Dundas Cottage, Castlecary.
1919. Weir, John, M.A., Ph.D., Geological Department, University.
1901. Wight, E. Hall, 150 Hope Street, Glasgow.
1924. Wilson, Isobel, 26 Derby Crescent, Glasgow.
1916. Wingate, John B., 208 St. Vincent Street, Glasgow.
1912. Wordie, James M., B.A., B.Sc., St. John's College, Cambridge.
1910. Wright, James, 36 Douglas Street, Kirkcaldy.
1902. Young, Arch. A., 2 Parkgrove Terrace (West), Glasgow.
1920. Young, J. S., Mossgiel, Larbert.

Digitized by Google

INDEX TO VOLUME XVII.

1924-26.

	PAGE
Accounts, abstracts of	166, 342, 474
Apatites in Sedimentary Rocks, as indicators of atmospheric carbonic acid	407
Arran, Permian Breccia of	264
Barrett, B. H.	264, 402
Benmore Hill, Cowal, Fissures in	69
Boulder Clay of S.W. Scotland	354
Burrows in Sandstone, Fife	77
Carbonic Acid, atmospheric, apatites in Sedimentary rocks as indicators of	407
Carboniferous strata below the top Hosie Limestone of Ayrshire	204
Chitons of Woodmill	75
Clyde Alluvium, petrography of	402
Coelonautilus multicarinatus	78
Columnar structure	63
Composite intrusion at Bennan	173
Corries, Spitsbergen	43
Crassiventer, Solenocheilus	78
Cyclostomus ,, ...	79
Deutozoic rocks of Scotland	105
Devonian of England and Wales	121
,, Central Europe	124
,, Russia	124
,, N. America	128
Discites, oxystomus	78
Dolerite Boss of Sithan-t-Sluain	426
Erosion, Spitsbergen	43

Digitized by Google

PAGE
Fracture in homogeneous media 50
French, Dr. James 50
Fissures in strata of Benmore Hill 69
Flett, W. R. 396, 398

Geographical Conditions in Ayrshire near the close of Calciferous Sandstone Times 214
Geology of Iceland 185
Geology of the Tarbert District of Loch Fyne 233
Glaciers of Spitsbergen 1
Glacial Sequence of S. W. Scotland 354
Gregory, C. J. 91
,, Prof. J. W. 354, 438

Harrison, J. V. 173
Holmes, James 426

Iceland, Geology of 185
,, Petrography 271
Intrusion, composite, at Bennan 173

Kentallenite, Boulders of, near Greenock 422
Kidston, Dr. R. 464
Knapdale, South (Argyll) 377

Loch Tulla, Parallel Roads of 91

McCallien, W. J. 233, 377
McCulloch, Rev. D. 422
Macgregor, John 69
Mackie, Dr. W. 407
Macnair, P. 105
Manson, W. 349
Megatherium bones from Peru 181
Metamorphic Zone near Moniaive 438
Moraines of S.W. Scotland 354
Multicarinatus, coelonautilus 78
Murdoch, J. A. W. 181

Nautili, notes on four 78
North Ayrshire, Carboniferous strata in 204

Digitized by Google

PAGE
Obituary 464
Occurrence of *Sanguinolites abdenensis* 349
Old Red Sandstone of England and Wales.. 121
,, ,, Scotland 105, 115
,, ,, Spitsbergen 126
Oxystomus discites 78

Palagonite in Iceland 308
Parallel Roads of Loch Tulla 91
Patton, Dr. D. 80, 464
Peacock, Dr. M. A. 185, 271
Permian Breccia, Arran 264
Peru, Megatherium Bones 181
Petrography of Clyde Alluvium 402
,, Iceland 271
Plant Distribution, River action and its bearing on .. 80
Proceedings 146-163, 334-340, 466-472

Red Sandstone of Toward 169
Richey, James E. 204
River Action and its bearing on Plant Distribution .. 80
Rhinoceros bone from Cadder 395
Roads, Parallel, of Loch Tulla 91

Sandstone, burrows in Fife 77
,, Red of Toward 169
Sand deposit at Torrance 396, 398
Sanguinolites abdenensis 349
Solenocheilus crassiventer 78
,, *cyclostomus* 79
Spitsbergen, Glaciers of 1
Stark, James 169
Stevens, Alex 440
Structure Lines, World Geometry of 440
Swinton, W. E. 395

Tarbert District of Loch Fyne 233
Toward, Red Sandstone of 169
Tyrrell, Dr. G. W. 1

Volcanic periods in Iceland 323

World Geometry of Structure Lines 440

Digitized by Google

PRINTED BY
TITUS WILSON AND SON, 28, HIGHGATE
KENDAL

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

14 DAY USE
RETURN TO DESK FROM WHICH BORROWED
EARTH
SCIENCES
LIBRARY
This book is due on the last date stamped below, or on the date to which renewed.
Renewed books are subject to immediate recall.

JUN 7 1962
JUL 18 1975
INTERLIBRARY LOAN
JUN 19 1975
UNIV. OF CALIF., BERK.
APR 15 1976

LD 21–50m-6,'60
(B1321s10)476

General Library
University of California
Berkeley

Digitized by Google